THE UNIVERSITY OF ALBERTA

# A STUDY OF MEDICINE HAT SANDSTONE

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "A Study of Medicine Hat Sandstone", submitted by Khwaja Gulzar Ahmad B. Sc.(Hons.) M. Sc., in partial fulfilment of the requirements for the degree of Master of Science.

## ABSTRACT

The geometry, origin and environments of deposition of the Medicine Hat Sandstone Member of the Upper Colorado Shale (Upper Cretaceous) in southeastern Alberta and southwestern Saskatchewan were investigated by examining core from 35 wells and by lithological interpretation of 317 electric and 488 radiation logs.

The reservoir consists of an east-west trending, elongated lenticular body of quartz rich lithic sandstone. Rock fragments consist of chert, shale and coaly material. Matrix is the primary binding material but calcite cement is also sporadically distributed in the sandstone. Three detrital clay minerals, kaolinite, illite and chlorite are present in the sandstone. Except for pyrite, which is authigenic, all components of the sandstone are probably reworked coarser components of the enclosing Colorado Shale. The sand was probably deposited on a relatively flat shoal by weak waves and currents in a shallow sea.

Data obtained from electric and radiation logs for 22 common wells, and by systematically sampling maps of the same surface or interval based on these two sources, were compared statistically by using a simple linear regression model. Isopach values from the two sources have a very poor statistical correla-

tion (R) whereas structural elevations are statistically comparable and can be combined for the construction of maps and cross sections. The degree of correlation may be dependent on the density of well control.

Thicknesses of sand in the Medicine Hat Sandstone Member, calculated from 5 millivolts and 10 millivolts minimun spontaneous potential are statistically comparable with higher values obtained using the 5 millivolts deflection.

A similarity of structural features on top of the Medicine Hat Sandstone and top of the Colorado Group shown by contoured maps for the two surfaces is supported by results obtained from a statistical comparison of the structural elevation data for the two surfaces.

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# CHAPTER ONE - INTRODUCTION

## General Statement

The development of the Medicine Hat, Hatton and Horsham gas fields of southeastern Alberta and southwestern Saskatchewan began in 1904 with the discovery of natural gas by the Canadian Pacific Railway Company in an Upper Cretaceous sandstone near the town of Medicine Hat. Extensive drilling and extension of production has been accomplished in the last 65 years. The area occupied by these fields is shown on Figures 1 and 2. Since 1904 some 472 wells capable of producing gas have been completed in the Medicine Hat Gas pool alone, and 374 of these wells have given a total cumulative production of 567, 003, 858, 000 standard cubic feet of gas to the end of October, 1968. In Saskatchewan (Hatton-Horsham fields) a total of 213 wells have been completed and 40, 021, 846,000 standard cubic feet of gas have been produced by the end of June, 1968. A detailed study of the reservoir rock, the Medicine Hat Sandstone was undertaken for the following reasons:

1. No detailed work on the geologic aspects of the fields and reservoir sandstone has so far been published, and only a few general compilation works on the fields are available in the published literature.
2. Data in the form of different kinds of mechanical

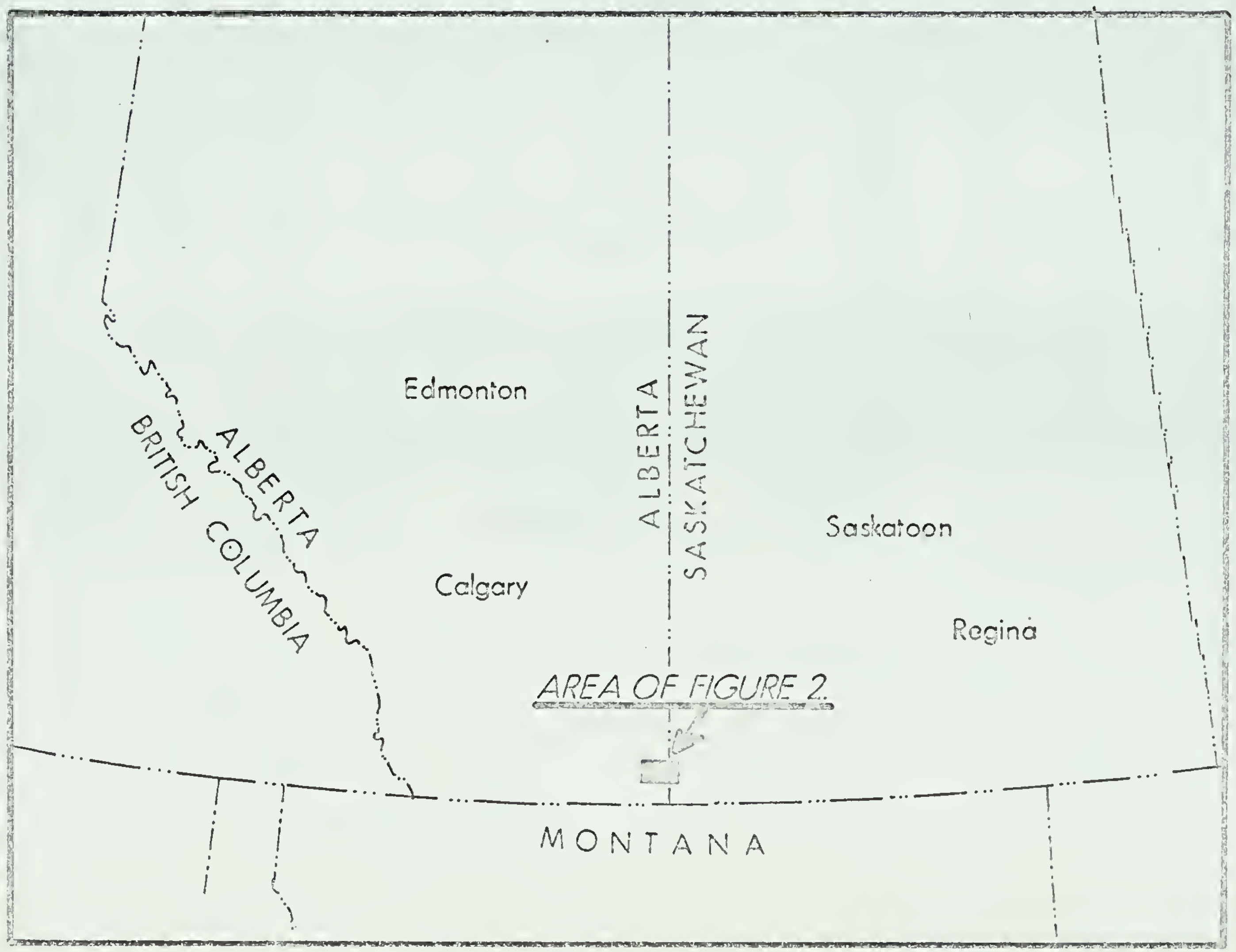



FIGURE 1.- INDEX MAP OF FIGURE 2.

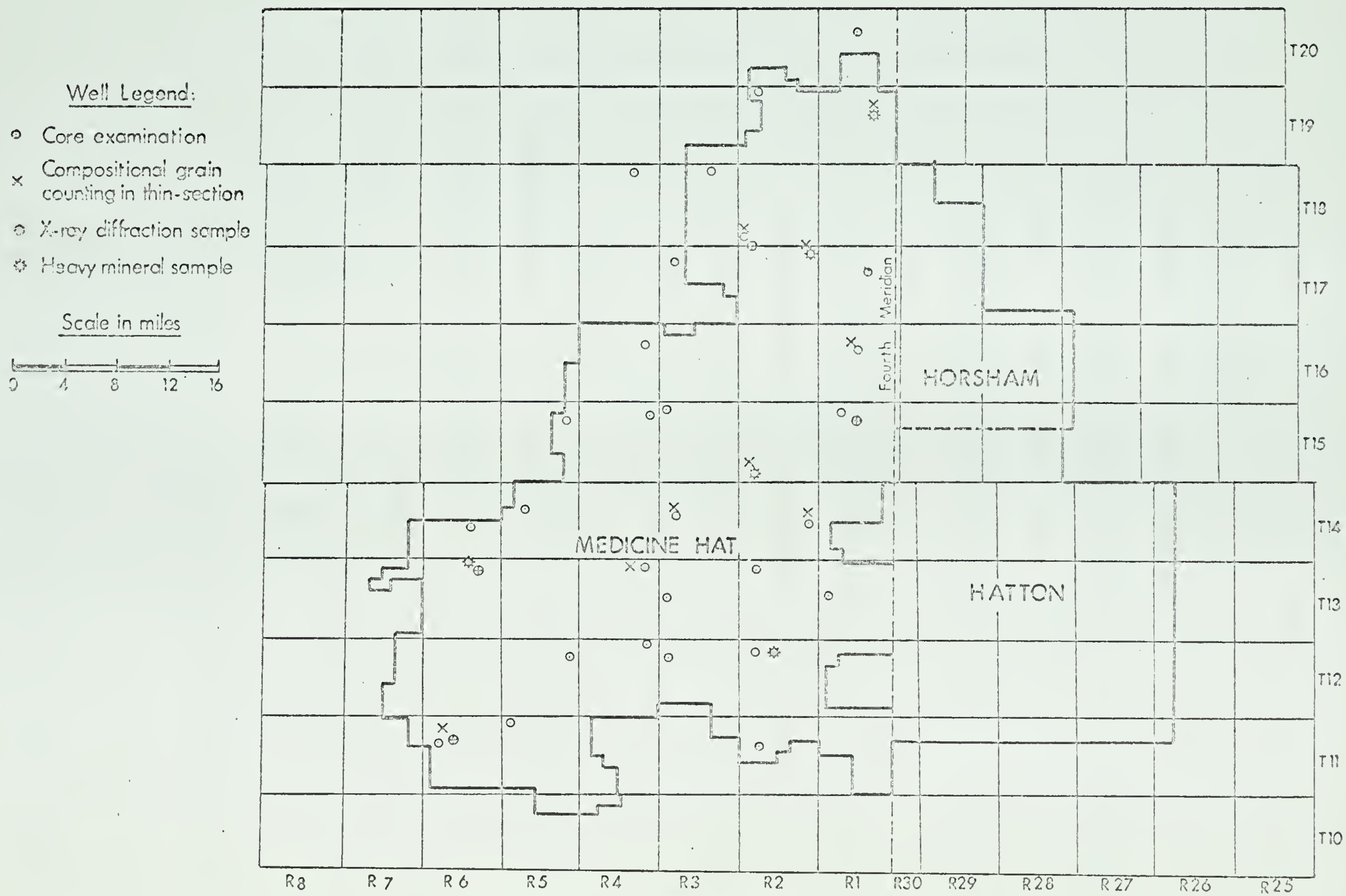



FIGURE 2. Medicine Hat — Hatton — Horsham Fields
(Alberta and Saskatchewan)
Showing Control Points

logs at a spacing of 640 to 1280 acres provide reliable control for carrying out a detailed study of the reservoir sandstone.

3. 3900 feet of core is available at the Oil and Gas Conservation Board in Calgary from the Medicine Hat Gas pool, and a few hundred feet of core from the Hatton and Horsham pools is stored by the Department of Mineral Resources in Regina.

4. The extensive area underlain by the Medicine Hat Sandstone and its large production and estimated reserves make it an important as well as logical unit for detailed examination from the standpoint of geology.

Within the above mentioned broad perspective, the aims of the study were defined as follows:

i. To determine the geometry of the reservoir sandstone and the genetic relationship it has with the enclosing Colorado Shale.

ii. To establish the environment of deposition of the sandstone and its provenance.

iii. To compare qualitatively the electric and radiation logs used in the study to determine their general relationship and relative usefulness.

## Scope of the Work

In the subsurface the geometry of a lithologic unit is usually reconstructed on the basis of various kinds of electric and radiation logs, which was the approach taken in this study.

Core from 35 wells from the Medicine Hat field was studied with the help of the binocular microscope, and samples were taken at 5 foot intervals in the sandy zone. A petrographic study of twenty thin sections was made and X-ray determination of clay minerals was done on four samples. The heavy mineral contents of five samples were studied.

A total of 317 electrical logs and 488 radiation (Gamma Ray) logs were separately utilized for the stratigraphic analysis of the Medicine Hat, Hatton and Horsham fields. The data from these two different kinds of mechanical logs was evaluated and compared by statistical methods utilizing the IBM 360/67 computer.

## Previous Work

Although the Medicine Hat gas field is one of the oldest and one of the biggest gas fields in Canada, very little has been published in detail on the geological aspects of the reservoir sandstone.

Dowling (1916) treated the reservoir sandstone as a part of the overlying Milk River Sandstone, ascribed a thickness of up to 20 feet to it and considered it a shallow water deposit.

Dowling, Slipper and McLearn (1919) in the course of investigations of gas and oil fields in Alberta, Saskatchewan and Manitoba pointed out the thinning of the gas-bearing sand beds to the east and their not being definitely recognizable north of the Bow Island Anticline. They sketched the distribution of the gas-bearing sands on the basis of limited information available at that time.

Ross (1926, p. 487) referred to this horizon as the Medicine Hat Gas Sand and seems to have been the first person to do so in published literature. He described it as "...closely grained sand approximately 20 feet in thickness in the Milk River Sandstone at a depth of approximately 1,100 feet."

Williams and Dyer (1930) also regarded the gas-producing horizon as being the Milk River Sandstone and assigned the correct top to the gas sand at about 1,195 feet above sea level in the vicinity of Medicine Hat.

Spratt (1931), on the basis of drilling results available at that time, considered the sand as occurring in the upper Colorado Shale about 300 feet stratigraphically below the Milk River Formation with which it was previously correlated. He was therefore the first worker to recognize the correct stratigraphic position of the reservoir Medicine Hat Sandstone in the Upper Cretaceous strata of southern Alberta and Saskatchewan.

Hume (1933) referred to the reservoir as the Medicine Hat

Gas Sand, gave it an elevation of 1,000 feet above sea level, and pointed to the structural control of the accumulation of gas. He also placed the sand 80' - 90' below the top of the Colorado Shale.

Russell and Landes (1940, p. 25) commented that "... the only important sandy zone in this part of southern Alberta is the Medicine Hat Gas Sand occurring about a hundred feet from the top of the Colorado Formation and formerly identified as the Milk River Sandstone."

McCord (1957) described the sand as the Medicine Hat Member of the Colorado Shale, occurring at an average depth of 1,150 feet, noted its lenticular shape thinning to the west, north and east and pointed to the presence of a porosity barrier on the updip southwest margin of the field. He considered the arenaceous material to have been concentrated on a shoal in a shallow sea, and in support of this idea he pointed to the argillaceous, poorly sorted, variable character of the reservoir sandstone.

Williams and Burk (1964) described the Medicine Hat Sandstone as very fine grained, salt and pepper sandstone with lenses having considerable areal extent throughout southern Alberta and southwestern Saskatchewan, occurring 80 feet to 100 feet below the top of the Colorado Group and having a thickness of up to 45 feet with individual sandstone bodies being discontinuous and completely enclosed in shale. They considered the Medicine Hat Sandstone to

represent an increase in the supply of coarse clastics from the southwest.

Martin (1965) described this sand as occurring about 80 feet below the top of the Colorado Shale, having a variable thickness from zero to 45 feet and being remarkably uniform at about 30 feet over most of the field. He added that the clean sand content, though representing up to three-quarters of the gross section, shales out to zero on the edge of the pool. He suggested marine deposition from a series of deltaic distributaries along a coast line of low relief.

Hancock and Glass (1968) described the Medicine Hat Sandstone as being approximately 90 feet below the top of the Colorado, consisting of greyish to salt and pepper, very fine grained quartz sandstone with an argillaceous content, having a maximum thickness of 35 feet, a width of 5 to 8 miles, a length of 35 miles, trending east to west, and disappearing entirely beyond the northwest and northeast sides of the fields.

## Method of Investigation

All the electric and radiation logs available for the area shown on Figure 2 were first collected from different sources and studied separately. The Milk River Sandstone, Colorado Shale (First [Upper] White Specks), tops and top and bottom of the Medicine Hat Sandstone were identified on the logs and the respective

depths were recorded. To maintain consistency in picking the formation tops, a network of correlation cross sections was established for each kind of log separately at an approximate spacing of 18 miles, running south to north and west to east in the area under study. All the adjoining logs were then correlated into these loops by closely comparing the curve characteristics of each log to the curve characteristics of logs in the correlation sections, thus guaranteeing the consistency and uniformity of the data from the logs of the whole field. This procedure, though a little time-consuming, was found to be very effective and useful for this purpose.

The tops and bottoms of the units picked from the logs provided the basis for constructing maps and cross-sections for the purpose of determining the shape, size and extent of the reservoir. In addition, the net thickness of sand in the Medicine Hat Sandstone Member was determined by separately totalling the thickness of sections exhibiting negative spontaneous potential values (on the electric logs) of greater than five and ten millivolts respectively from the "Shale line" (Fig. 3). Separate isolith maps were prepared for each of these values.

In the majority of the wells only one of the two kinds of logs used in the study was available, but 46 wells were found to have both electric and radiation (Gamma Ray) logs, and in the case of these wells where a discrepancy in the values of the "picks" was observed,

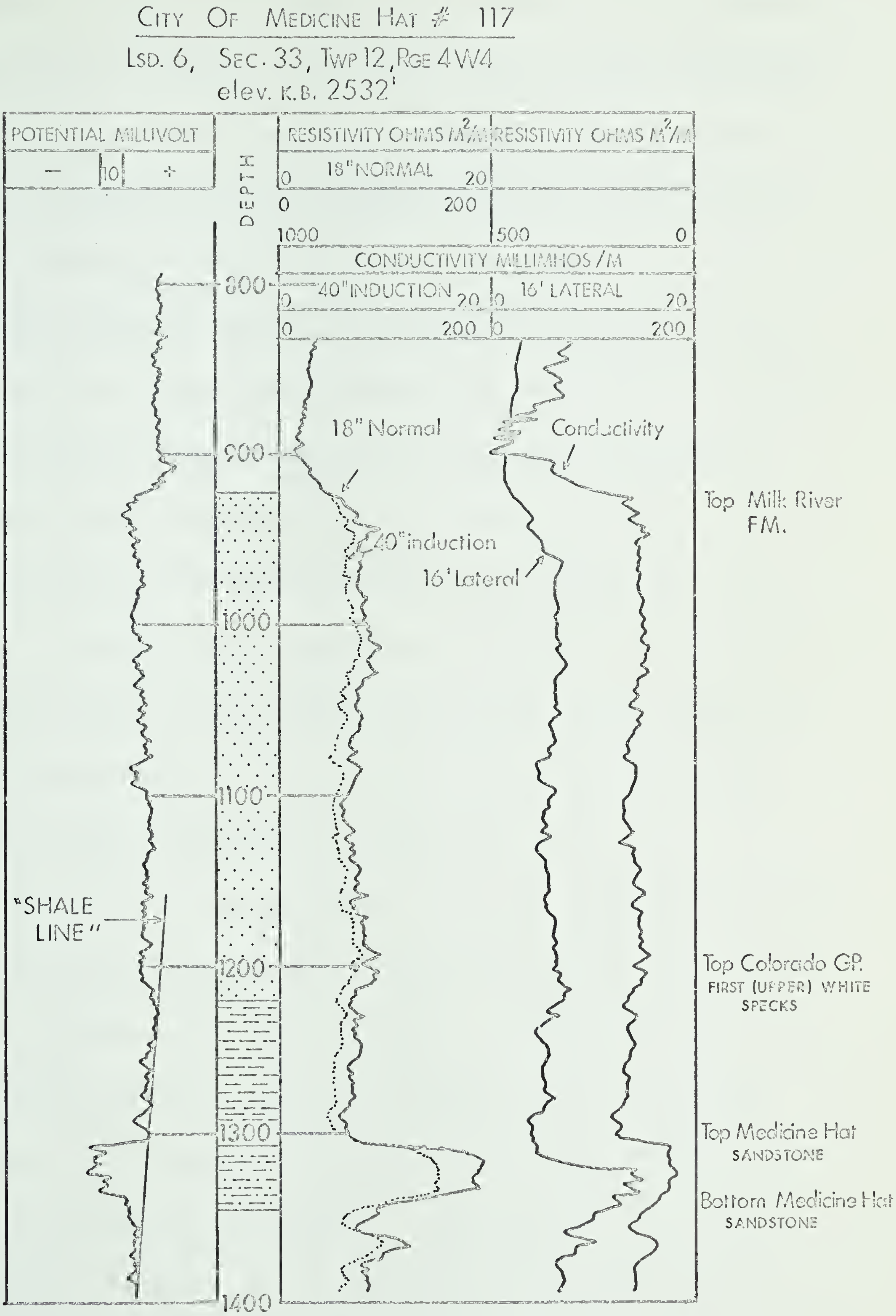



FIGURE 3 -- Position of Shaleline on the Spontaneous Potential Curve of the Electric Log.

the radiation log values were taken to be reliable and were used for the construction of maps etc. Only 22 of these 46 wells were logged for the complete section from the top of the Milk River Sandstone to the bottom of the Medicine Hat Sandstone, and these were used for qualitative comparison of electric and radiation logs.

Maps using data obtained exclusively from the 317 electric logs showed a poor and scattered control and were considered to be less useful than the maps based on the data from the radiation (Gamma Ray) logs. Hence some of these two sets of maps were used separately for interpretation purposes. A third set of maps was prepared using combined data from both electric and radiation (Gamma Ray) logs, and these maps were used for interpretation if a good correlation between the two sources of data was found by applying statistical techniques to compare the data.

A detailed microscopic examination of the core from 35 wells in the Medicine Hat Gas pool area, selected on the basis of one well from each township block, was carried out. Chip sampling of the sandy zones at an interval of 5 ft. was done in the cores having sandy zones, and samples from the upper and lower contacts, if present in the core, were also taken. These samples were used for detailed petrographic, X-ray diffraction and heavy mineral studies. From 80 thin sections, twenty were selected for a detailed petrographic study. A staining technique (Hayes and Klugman, 1959)

was applied to differentiate between potash-feldspar, plagioclase and quartz. Grain compositional counts of more than 200 points on each of nine samples were done for sandstone classification.

Heavy minerals from five samples, extracted by using tetrabromoethane (S. G. = 2.94 @ 20°C), were mounted in Aroclor (n = 1.66) and identified.

X-ray diffraction was applied to four samples from the Medicine Hat Gas pool area to determine the types of clays present in the Medicine Hat Sandstone. Locations of thin sections, heavy mineral samples and clay samples are given in Appendix A.

Use of Computer in Stratigraphic Analysis

A systematic sampling of the data from 4 comparable sets of maps, including isopach and structural contour maps of the fields constructed using electric and radiation logs separately and a map with combined data from both sources was done by laying a grid with sample points 3 miles apart. In all, 254 observations from each of the maps were made and punched on computer cards. The computer was utilized to compare the different sets of observations and give the coefficient of correlations between the different pairs of observations. In this way these 9 maps were compared in pairs. The isolith values of reservoir sandstone for 5 millivolt and 10 millivolt deflections from the "Shale line" on the spontaneous potential curve of the electric logs were also compared, and isolith

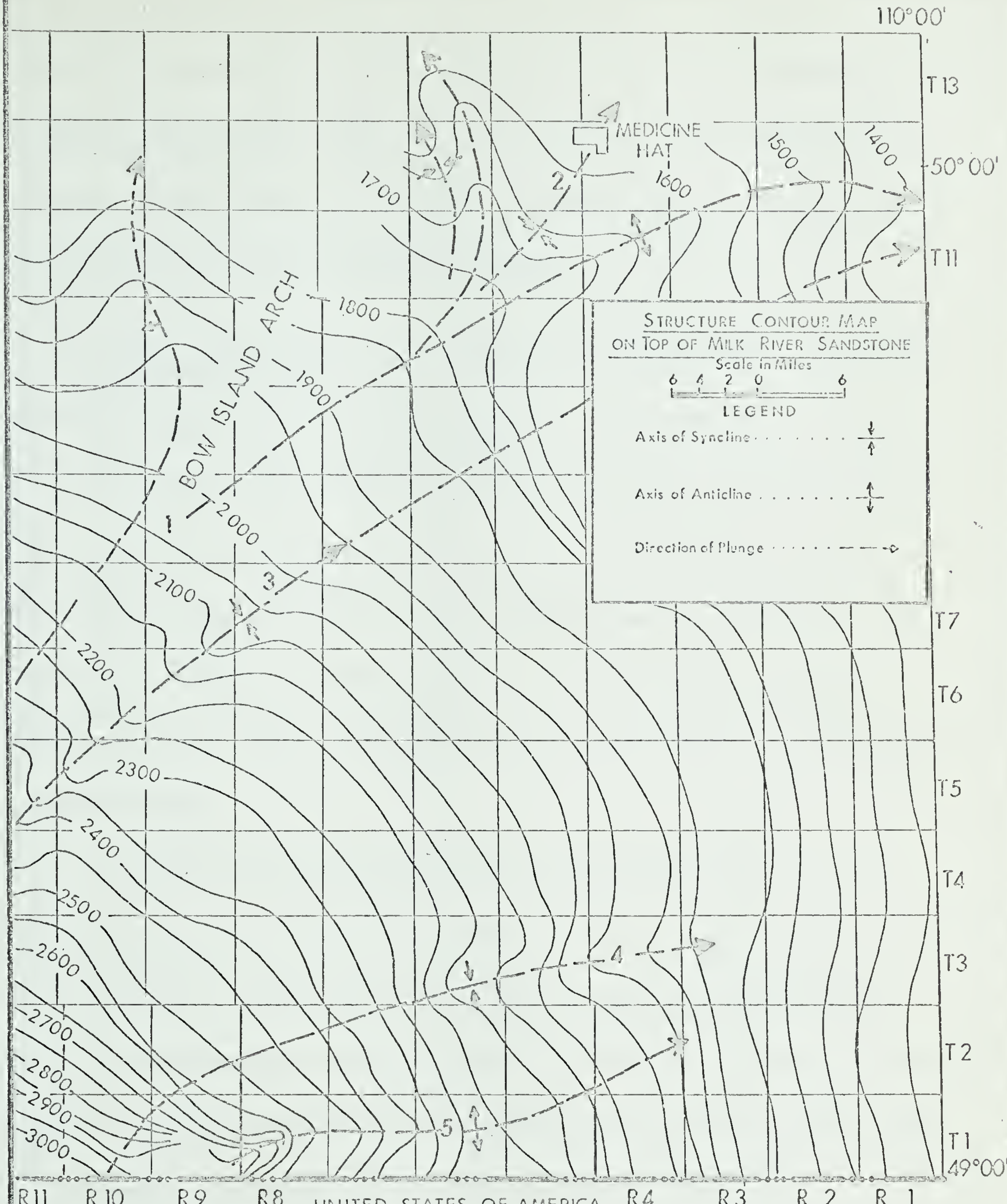
values were in turn compared with the structural elevations at the top of the Medicine Hat Sandstone to determine whether any relationship existed between the structural configuration and the thickness of the sand at any particular location in the area of study.

## CHAPTER TWO - STRUCTURE AND STRATIGRAPHY

### Structural Setting

General Statement: The area under study lies on the eastern flank of the Sweetgrass Arch, a dominant Tertiary feature with a history of activation dating back to Jurassic or Mississippian times. The Sweetgrass Arch was originally considered to be a single large anticlinal uplift with a width of 40 to 70 miles and an approximate length of 200 miles extending from the Little Belt Mountains in Montana into southern Alberta where it supposedly veered to the northeast and finally lost its identity north of the city of Medicine Hat (Michner, 1934). Tovell (1958) showed that this tectonic feature is not a single unit but is a composite of three major components of different origins. Two of the components (South Arch or Teton Arch and the Kevin-Sunburst Dome) lie mainly south of the 49th parallel. The third feature, structurally more complicated than the others, lies in southern Alberta and was designated as the Bow Island Arch by Tovell (Fig. 4). Other local structural features in the vicinity of Medicine Hat have been described by Meyboom (1960).

The overall structural picture in the southern part of Alberta clearly reveals a radiating pattern of closely connected folds. The prominent direction of fold axes in the western part of the area is




LEGEND:

1. Bow Island Arch
2. Medicine Hat Structure
3. Foremost Structure
4. Lost River Structure
5. Black Butte Structure

(after Meyboom, 1960)

FIGURE 4. STRUCTURAL SETTING OF SOUTHEASTERN ALBERTA

to the west and northwest, and in the eastern part to the east and northeast (Meyboom, 1960, Fig. 4). The Bow Island Arch and the Medicine Hat Structure are briefly described below. The age of the structures is also briefly discussed.

Bow Island Arch: This feature (Fig. 5) first described and named by Slipper (1935) is located in Townships 10 and 11, Ranges 6, 7 and 8 West of the Fourth Meridian (Meyboom, 1960). Michner (1934) while discussing the extension of the Sweetgrass Arch into Alberta referred to this structure as an exception to the generally northwest trending structure of the Sweetgrass Arch and had described it as a low dome with 50 feet of closure and having commercial quantities of gas.

According to Tovell (1958) the Bow Island Arch resulted from the subsidence of the Williston Basin in the east and the Alberta syncline in the west as a result of crustal compressional forces. This explanation has been objected to by Meyboom (1960) who favoured primary vertical movements in the basement complex as the origin of the Arch. Activation in the plunging trend of the Bow Island Arch through the Paleozoic and Mesozoic has been pointed out by Tovell (1958). The structure contour map constructed by him on top of Exshaw (Mississippian) Formation shows a slight southwest plunge whereas the structural contour map on the top of the Milk River

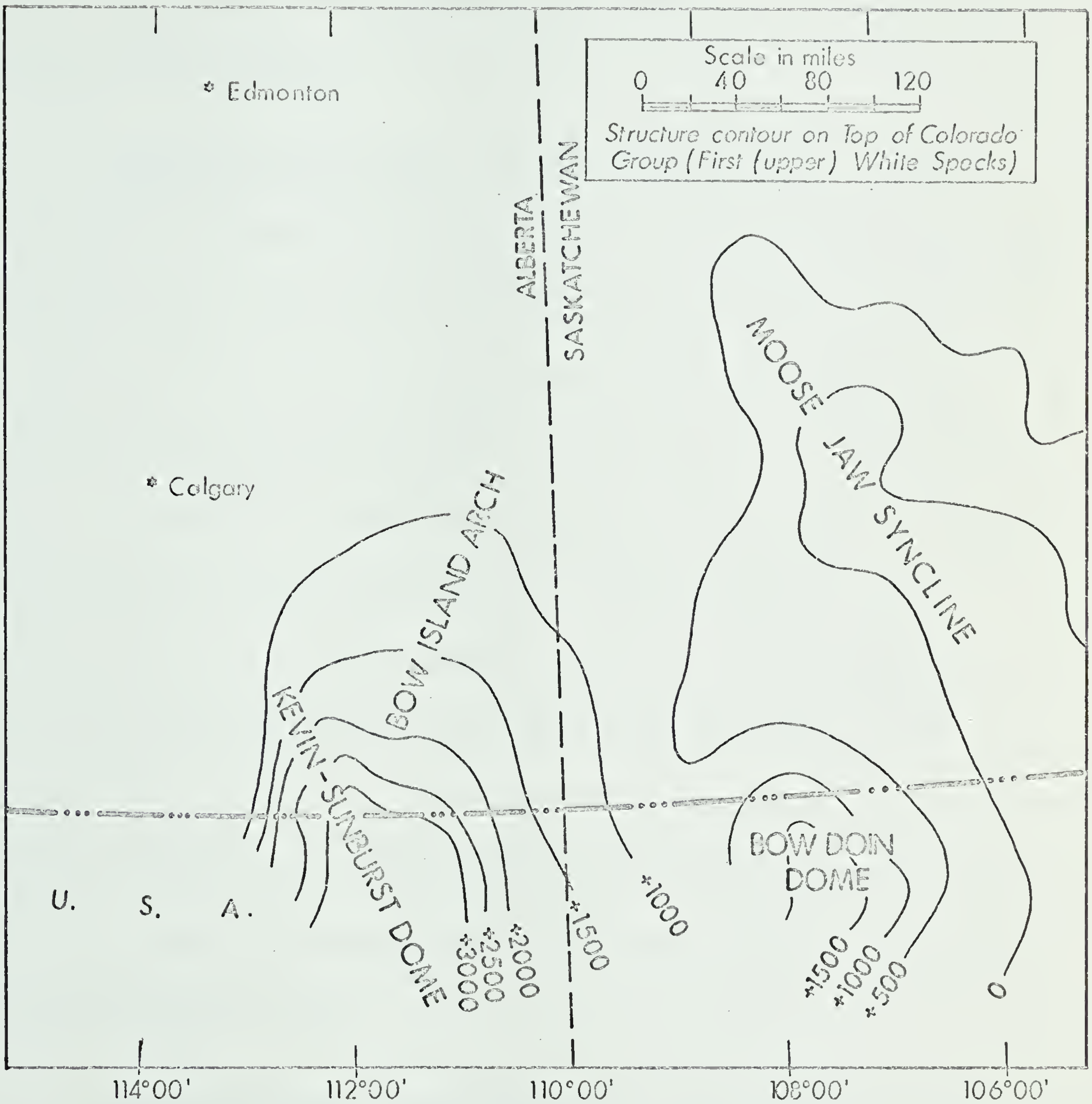



FIGURE 5- Main structural features in Southern Alberta and Saskatchewan (*after Williams and Burk, 1964*).

Formation indicates a northeast plunge. This reversal of the plunge has been attributed to the relationship between the total amount of uplift of the dome and the attitude of the Exshaw strata prior to the formation of the dome.

Medicine Hat Structure: Michner (1934) referred to this structure as southward plunging nose cut by an east west trough, and making up part of the northwest plunging Sweetgrass Arch (Fig. 5). A composite local structure consisting of a steep, asymmetrical anticline trending north in range 6 and a broader east trending anticline in Townships 11 and 12 which coalesce in Township 10, Range 6, West of the Fourth Meridian (Fig. 4) has been described by McCord (1957) as a saddle between the southwest plunging North Battleford high in Saskatchewan and the northeast plunging Bow Island Arch in Alberta. A reference to this structure in the vicinity of Medicine Hat was made by Michner (1934) who described it as the probable result of the northeastern extension of the anticlinal nature of the Sweetgrass Arch.

Age of Structures: Though the exact age of the Sweetgrass Arch is difficult to establish, Borden (1956) considered it to have existed since late Devonian or early Mississippian time. He considered it to be related to the older (Precambrian to late Devonian) southern Alberta Arch. He attributed the emergence of this structural

feature to the shifting of the center of uplift in southern Alberta to the Sweetgrass Arch during the late Devonian to early Mississippian times.

Michner (1934) and Wells (1957) have pointed to a difference in thickness of the stratigraphic section from the base of the Cambrian to the top of the Virgelle (Upper Cretaceous, lower Milk River) on the crest and flanks of the Sweetgrass Arch in Montana and southern Alberta. Thicker sediments are encountered on the flanks of the Arch and a comparatively thinner sedimentary section is observed on the crest of the Arch for this geological interval. The difference in the thickness of the sedimentary column is generally in the order of 500 feet. They have shown that the formations from at least Mississippian time to the end of the Colorado time show a distinct thinning over the crest of the Arch. Wells (1957), from a study of isopach maps for various geological intervals in southern Alberta, showed that there was a slight activation of the Sweetgrass Arch in its present form during Jurassic and Colorado (Upper Cretaceous) time. Though the partial erosion of strata younger than Colorado (Milk River, Belly River, Bearpaw and St. Mary River Formations) over the Sweetgrass Arch make conclusions derived from isopach studies of these units comparatively unreliable, it appears that there was no appreciable activity along the Sweetgrass Arch during the later part of the Upper Cretaceous time. The structure contour

maps constructed for southern Alberta on the Exshaw (Mississippian) and the Milk River (Upper Cretaceous) Formations by Tovell (1958) also suggest that the Sweetgrass Arch has been a positive feature since Devonian to early Mississippian time.

From the foregoing discussion it appears that the Bow Island Arch, a component of the Sweetgrass Arch, was active during the deposition of the Medicine Hat Sandstone during late Colorado time. The deposition of the Medicine Hat Sandstone therefore may have been partially or fully controlled by the structural setting in the area under study. The saddle-like structure called the Medicine Hat structure by Meyboom (1960) has been shown to be a controlling factor in the present configuration of reservoir sandstone (McCord 1957). The trap is stratigraphic in nature because it is formed by the sandstone shaling out in all directions, and the geometric shape of the reservoir sandstone body is the result of deposition in the tectonic framework existing at that time.

## Stratigraphy

General Statement: The Medicine Hat Sandstone, an extensive isolated sand body in southeastern Alberta and southwestern Saskatchewan, occurs approximately 80 to 110 feet below the top of the marine Colorado Shale (Fig. 3). The sandstone is 30 to 45 feet thick with thin lenses of shale of varying thickness intercalated within it. Contacts of the sandstone with the Colorado Shale are

gradational, and gradations from shale to sand and vice versa are distinctive features in the studied cored sections of this sequence. The Medicine Hat Sandstone thins and shales out in all directions from the Medicine Hat area.

The Medicine Hat Sandstone was deposited on the northeastern flank of the Sweetgrass Arch. According to McCord (1957) the clastics composing the sandstone were probably derived from an emergent area on the axis of the Arch.

The upper 160 to 190 feet of the Colorado Shale in which the Medicine Hat Sandstone occurs are generally composed of white speckled shale which has been correlated with the Niobrara chalk of the Black Hills region of the central United States. Upper Cretaceous strata above the Colorado Shale are mainly of continental to brackish water origin.

<u>Description of Stratigraphic Units:</u>

<u>Milk River Formation:</u> Dowling (1916) named the Milk River Formation and described the strata along the Milk River as slightly consolidated, shallow water sandstones. These beds underlie the Pakowki Shale and conformably overlie the Colorado Group. They consist of up to 300 feet of very fine to medium grained, grey, salt and pepper sandstone, siltstone and sandy to silty dark grey shale, including the transition beds at the base. Thicknesses of

up to 420 feet in the eastern part of the area under study are detectable from the electric and radiation logs. In outcrop the top of the formation is marked by a zone of black chert pebbles which lie at the base of the overlying Pakowki Shale. East and north of the outcrop area in southern Alberta, sandstones in the Milk River Formation rise stratigraphically towards the shale-out in the subsurface (Williams and Burk, 1964). Where the Milk River Formation shales out to the north and east, beds equivalent to it and to the overlying Pakowki Formation are known as the Lea Park Formation.

Meyboom (1960) equated the sandstones of the Milk River Formation in southern Alberta to the basal sandstone member of the Eagle Formation (Virgelle Sandstone Member) in Montana, although it is lithologically different.

The Milk River Sandstone has good aquifer qualities (Meyboom, 1960) and in places contains small accumulations of natural gas (Hancock and Glass, 1968). The Milk River Formation represents the first regressive deposits formed following the deposition of the Colorado shales. Deposition of coarse clastics was probably the result of an upwarp southwest of the region, with different lithologies representing different environments of deposition, namely, beach sands, lagoonal carbonaceous shales and local stream and deltaic deposits (Slipper and Hunter, 1931).

TABLE I MEDICINE HAT SANDSTONE AND ITS EQUIVALENT IN S. ALBERTA AND S. SASKATCHEWAN (AFTER WILLIAMS & BURK 1964)

| EPOCH | STAGE | SOUTHERN SASKATCHEWAN | CYPRESS HILLS | SOUTH-WESTERN ALBERTA FOOTHILLS |
|---|---|---|---|---|
| UPPER CRETACEOUS (PART) | CAMPANIAN | BEARPAW | | |
| | | BELLY RIVER | BELLY RIVER | BELLY RIVER |
| | | PAKOWKI | PAKOWKI | |
| | | MILK RIVER | MILK RIVER | |
| | | FIRST WHITE SPECKS | | |
| | SANTONIAN | UPPER COLORADO | UPPER COLORADO: M. HAT | ALBERTA: WAPIABI |
| | CONIACIAN | | | CARDIUM |
| | TURONIAN | SECOND | WHITE | SPECKS |
| | CENOMANIAN | | | |
| | ALBIAN (PART) | BASE OF FISH SCALES | | |

Upper Colorado Group: Hayden (1876) gave the name Colorado Group to the exposures at the base of the Rocky Mountain Ranges in Colorado (Alberta Society of Petroleum Geologists, 1960). In southern Alberta and Saskatchewan the strata between the base of the Fish Scales Marker and the top of the First (Upper) White Speckled Shale Zone is generally designated as the Upper Colorado Group of Cenomanian to Santonian age. It consists of a relatively uniform, thick section of dark to medium grey marine shale with minor sandstone, shaly limestone and bentonite horizons. The bentonite zones which are 2 to 4 inches thick are more frequent in the cored intervals of the shale in the northern part of the Medicine Hat Gas pool. The upper part of the shale contains small white specks composed of almost pure calcium carbonate, having a grain size of 0.01 mm. and occurring as small lenticles of chalk which have been gathered by compaction of the enclosing dark shale (Goodman, 1951).

The first (uppermost) appearance of these white specks marks the base of the overlying Milk River Formation and the top of the Colorado Shale. This zone is a very good marker horizon throughout western Canada, having wide use in the oil industry. The speckled shale unit normally has sharp contacts with both overlying and underlying strata (Robinson, 1968) but occasionally may grade upward into the Milk River Formation. In some cases this contact is not sharply defined in well logs.

Medicine Hat Sandstone Member: McCord (1957) designated the reservoir sandstone in the Medicine Hat area as the Medicine Hat Member of the Upper Colorado Formation which, according to him, lies between the First and Second White Speckled Shale Zone.

The Medicine Hat Sandstone has an average thickness of 30 to 40 feet with isolated areas of up to 50 feet in thickness and in common with other sands of the Colorado Group is thin bedded, shaly, marine, and composed of quartz and chert (Alberta Society of Petroleum Geologists, 1960). The sandstone is very fine to fine grained with angular to sub-rounded grains. The colour is variable from place to place being generally dependent on the shaly, silty and carbonaceous (coaly) material in it.

The Medicine Hat Sandstone has gradational contacts with the enclosing Colorado Shale, and streaks of shale of variable thickness in sand zones and sand lenses of variable thickness in shale sections are common. Gradations from very fine sand to fine sand with shale interlayers are also common.

Bedding is generally even and horizontal, though in a few instances cross-bedding was also seen. Small cut-and-fill type of structures were also observed to be comparatively common in the sandstone.

The sandstone is notable for its uniformity in composition, texture and structure over a wide area.

# CHAPTER THREE - STRATIGRAPHIC ANALYSIS

## General Statement and Limitations

In this study the basic stratigraphic data was obtained from the following sources:

i. Different kinds of mechanical logs run in the wells, mainly electric and radiation logs.

ii. Cores from 35 wells in the area of study.

Electric and radiation logs provided data on the structure, thickness, and areal distribution of the rock units in the area of study. Isopach, structure, and isolith maps and stratigraphic and structural cross sections, constructed on the basis of the data obtained from these logs provided the information about various stratigraphic units under study.

Data obtained from these logs is subject to several limitations. The shape and magnitude of deflection of the log curves are basically a record of the variation or contrast of electric or radiation response of the strata logged. However, additional factors such as variable sizes of boreholes (caving, etc.) and different types of drilling muds influence the response of the logging device, and the resultant shape of the curve is a reflection of the lithological variation as well as the influence of these factors. Therefore variation in these factors from well to well may produce curves for a similar stratigraphic section

which may be different quantitatively but comparable qualitatively.

Furthermore, the logs used in this analysis were produced by various logging companies with their patent logging techniques and in some instances using different scales for recording the parameters being logged. This factor alone often makes the quantitative interpretation of the logs unreliable.

In addition to these two main limitations the personal error in the process of lithological interpretation of both types of logs by a worker may be considered another significant limiting factor.

Marker horizons for the various subsurface stratigraphic units have been qualitatively determined by the curve characteristics of the logs. No attempt was made to examine the influence of various disturbing factors on the quantitative interpretation of the log curves for the purpose of this study.

The stratigraphic section involved in this study consists of sandstones and shales which have variable thicknesses. Generally the sandy zones are comparatively thin and are intercalated with shaly material. Contacts are gradational; the lower contact of the Medicine Hat Sandstone Member was found to be particularly difficult to determine on both types of logs.

A major limitation which was experienced in constructing the maps and cross sections was the absence of deep wells in the area. More than ninety percent of the wells studied penetrated only

the section down to the reservoir sandstone and therefore nothing can be said about the underlying strata.

Due to the difficulty of identifying the base of the Medicine Hat Sandstone Member, the structural configuration of the surface on which the reservoir sandstone was deposited cannot be determined. This study is therefore limited to the reservoir sandstone, the part of the Colorado Shale overlying the sandstone and the Milk River Formation.

## Marker Horizons

### Milk River Formation:

Electric Logs: The top of the Milk River Formation was found to be an extensive and easily identified marker horizon on electric logs. The distinctive decrease in spontaneous potential (deflection to the left) with a corresponding increase in the resistivity (deflection to the right) together were considered to mark the top of the Milk River Formation (bottom of the overlying Pakowki Formation) throughout the area.

Electric and radiation logs, indicating the typical "picks" for all the marker horizons discussed above are shown in Appendix B.

Radiation Logs: On radiation logs it was observed that the top of the Milk River Formation was difficult to pick in some

cases. In the majority of cases, a gradual increase in the gamma radiation (deflection of the curve to the right) and a corresponding decrease in the response on the neutron curve (deflection towards right) was taken to mark the change in the lithology from the Pakowki Formation to the silty, shaly sandstone of the Milk River Formation.

<u>Colorado Group (First [Upper] White Specks):</u>

<u>Electric Logs:</u> The top of the Colorado Group which is designated by the first appearance of white specks below the Milk River Formation, is a very extensive and very good marker horizon on electric logs, and is easily traccable throughout the entire Western Canada Sedimentary Basin.

The characteristic "pick" for the top of the Colorado Group (bottom of overlying Milk River Formation) represents the lithological change from the impure shale and silty sandstone above to calcareous speckled shale below, and ideally should make a good marker horizon on electric logs. Due to the silty nature of the transitional zone the "pick" for the top of the Colorado Group is found to be unclear in some logs. Generally the spontaneous potential curve of the electric log shows a comparatively sharp deflection towards the right and the inflection point on this curve was taken as the top of the Colorado Group in this study.

The response on the resistivity curve is indistinct in the corresponding zone and therefore it can seldom be used for marking

the top of the Colorado Group in this area, though to the north (Burk, 1962; Khamesra, 1963) the resistivity curve has been reported to have a good "pick" for the top of the Colorado Group.

Radiation Logs: The top of the Colorado Group (First [Upper] White Specks) on the gamma ray curve, a sharp increase in the intensity of radiation, is a very distinct and characteristic marker which can easily be traced throughout the area. A corresponding decrease on the neutron curve is usually present but is not consistent.

Top of the Medicine Hat Sandstone Member:

Electric Logs: The Medicine Hat Sandstone contacts with the overlying and underlying marine Colorado Shale are usually distinguished easily on the spontaneous potential and resistivity curves of electric logs. The top of the Medicine Hat Sandstone occurs generally 80 to 110 feet below the top of the Colorado Group and is marked by a sharp leftward deflection on the spontaneous potential curve. This deflection may vary in its intensity from area to area or from well to well, reflecting variations in the shaliness of the sandstone and/or the contrast in resistivity between the formation fluid and the fluid in the well when it was being logged.

On the resistivity curve the top of the Medicine Hat Sandstone is marked by a sharp deflection to the right, indicating the higher

resistivity of the sandstone as compared to the overlying Colorado shale.

Radiation Logs: A sharp decrease in the gamma radiation, and an increase in the neutron response were chosen as the criteria for marking the top of the Medicine Hat Sandstone. These deflections, though varying in their intensities, were found to be quite extensive, persistent and traceable throughout the area. No attempt was made to separate shaly streaks from the sandstone units on the basis of the curve characteristics on the logs because of the thinness of the sandstone unit. The total interval between the top and bottom of the sandstone marked on these logs was therefore considered to be the total thickness of the sandstone.

Base of the Medicine Hat Sandstone Member:

Electric Logs: The bottom of the Medicine Hat Sandstone was relatively difficult to pick on the electric logs because:

(a) Most wells did not penetrate sufficient shale below the sandstone to be indicated on the logs.

(b) The lower contact of the Medicine Hat Sandstone is gradational over an interval of at least 10 to 15 feet.

The spontaneous potential curve was therefore found to be of little use for determining the base of the Medicine Hat Sandstone. The resistivity curve however, was more consistent in the contact

zone and could generally be used to determine the base of the sandstone.

Radiation Logs: Radiation logs also indicated the abrupt ending of drilling and logging in the transition zone between the sandstone and shale. The gamma ray and neutron curves appear to record the change in lithology from sandstone to shale better than do the electric log curves. The gradation from sand to shale is marked by an increase in the gamma radiation intensity with a corresponding decrease on the neutron curve.

## Lithofacies of the Medicine Hat Sandstone Member

In addition to the above mentioned data, two values for the net thickness of sandstone in the Medicine Hat Member were calculated from the spontaneous potential curve of the electrical log.

An arbitrary baseline on the spontaneous potential curve was drawn as a straight line passing through all the points of maximum positive excursion of the curve. Thicknesses of section exhibiting deflections of 5 millivolts and 10 millivolts to the left from the baseline were arbitrarily considered to represent sands and each value was recorded separately. Two total thicknesses of sand were thus

obtained by adding thicknesses having 5 millivolt deflection or higher and those having 10 millivolt or higher deflection. The values thus obtained were different from the isopach values obtained either from the two types of logs or from the core study. All the electric logs did not show deflections greater than 5 millivolt, and of 317 electric logs, only 202 logs had indication of sandstone as defined above. It should be mentioned here that due to the limitations of the electrical logging techniques, and the influence of the various disturbing factors discussed earlier, values calculated on an arbitrary basis such as this may not be a true representation of the actual sandstone thickness in these wells.

Analytical Procedure:

Data Presentation: Data obtained from the electric and radiation logs independently include the following:

i. Isopach values for the interval between the top of the Milk River Formation and the top of the Colorado Group (First [Upper] White Specks).

ii. Isopach values for the interval between the top of the Colorado Group (First [Upper] White Specks) and the top of the Medicine Hat Sandstone Member.

iii. Isopach values for the Medicine Hat Sandstone Member.

iv. Elevations of the top of the Medicine Hat Sandstone Member with respect to sea level.

v. Elevations of the top of the Colorado Group (First [Upper] White Specks) with respect to sea level.

vi. Net sandstone thickness in the Medicine Hat Sandstone Member using 5 millivolt cutoff on spontaneous potential curve (electric logs only).

vii. Net sandstone thickness in the Medicine Hat Sandstone Member using 10 millivolt cutoff on spontaneous potential curve (electric logs only).

The following maps were constructed. Computer outputs in Appendix D also carry these designations.

Map 1 Isopach Map - Top Colorado Group (First [Upper] White Specks) to top Medicine Hat Sandstone Member - electric log data

Map 2 Isopach Map - Top Colorado Group (First [Upper] White Specks) to top Medicine Hat Sandstone Member - radiation log data

Map 3 Isopach Map - Medicine Hat Sandstone Member - electric log data

Map 4 Isopach Map - Medicine Hat Sandstone Member - radiation log data

Map 5 Structure Contour Map - Top of the Medicine Hat Sandstone Member - electric log data

| | |
|---|---|
| Map 6 | Structure Contour Map - Top of the Medicine Hat Sandstone Member - radiation log data |
| Map 7 | Structure Contour Map - Top of the Colorado Group - electric log data |
| Map 8 | Structure Contour Map - Top of the Colorado Group - radiation log data |
| Map 9 | Structure Contour Map - Top of the Medicine Hat Sandstone Member - electric log plus radiation log data |
| Map 10 | Structure Contour Map - Top of the Colorado Group - electric log plus radiation log data |
| Map 11 | Isolith Map - Medicine Hat Sandstone Member (10 millivolt S.P. deflection) - electric log data |
| Map 12 | Isolith Map - Medicine Hat Sandstone Member (5 millivolt S.P. deflection) - electric log data |

Maps 1, 2, 3, 4, 9, 10, and 12 are illustrated as figures 6 to 12 respectively.

Six cross sections were constructed along and across the long axis of the sandstone body, using the top of the Colorado Group

as a stratigraphic datum and the +1,000 foot elevation plane as a structural datum. As the cross sections did not reveal anything of significance not shown by the maps, they are not illustrated and will not be discussed further.

Analysis of Data: Both electric and radiation logs were avilable for only 46 wells in the area and of these wells only in 22 were all marker horizons for the units under study present. The comparative values for different isopachs and structural elevations from both logs in the 22 wells were obtained and a comparative chart (Table II) was prepared on the basis of these values. A comparison of isopach and structural elevations for the units involved suggests that structural elevation values can be better compared than the isopach values. Though these 22 wells are scattered all over the area and the results obtained from the comparison have a representative nature and can be broadly applied to determine the degree of relationship existing between the data from these two sources in this area, it was felt that a rigorous statistical comparison of the data would provide more meaningful results.

According to Krumbein and Graybill (1965, page 7) five classes of statistical questions commonly arise in geological studies:

1. Estimation of the mean values of measurable properties of the population.

Figure 6

MEDICINE HAT-HATTON-HORSHAM FIELDS
(Alberta & Saskatchwan)

ISOPACH MAP

TOP OF COLORADO GROUP
(First (upper) white specks)
TO
TOP OF MEDICINE HAT SANDSTONE

(CONTOUR INTERVAL = 10 FEET)

LEGEND

Wells with Electric logs

0 1.5 3.0 4.5 6.0
SCALE IN MILES

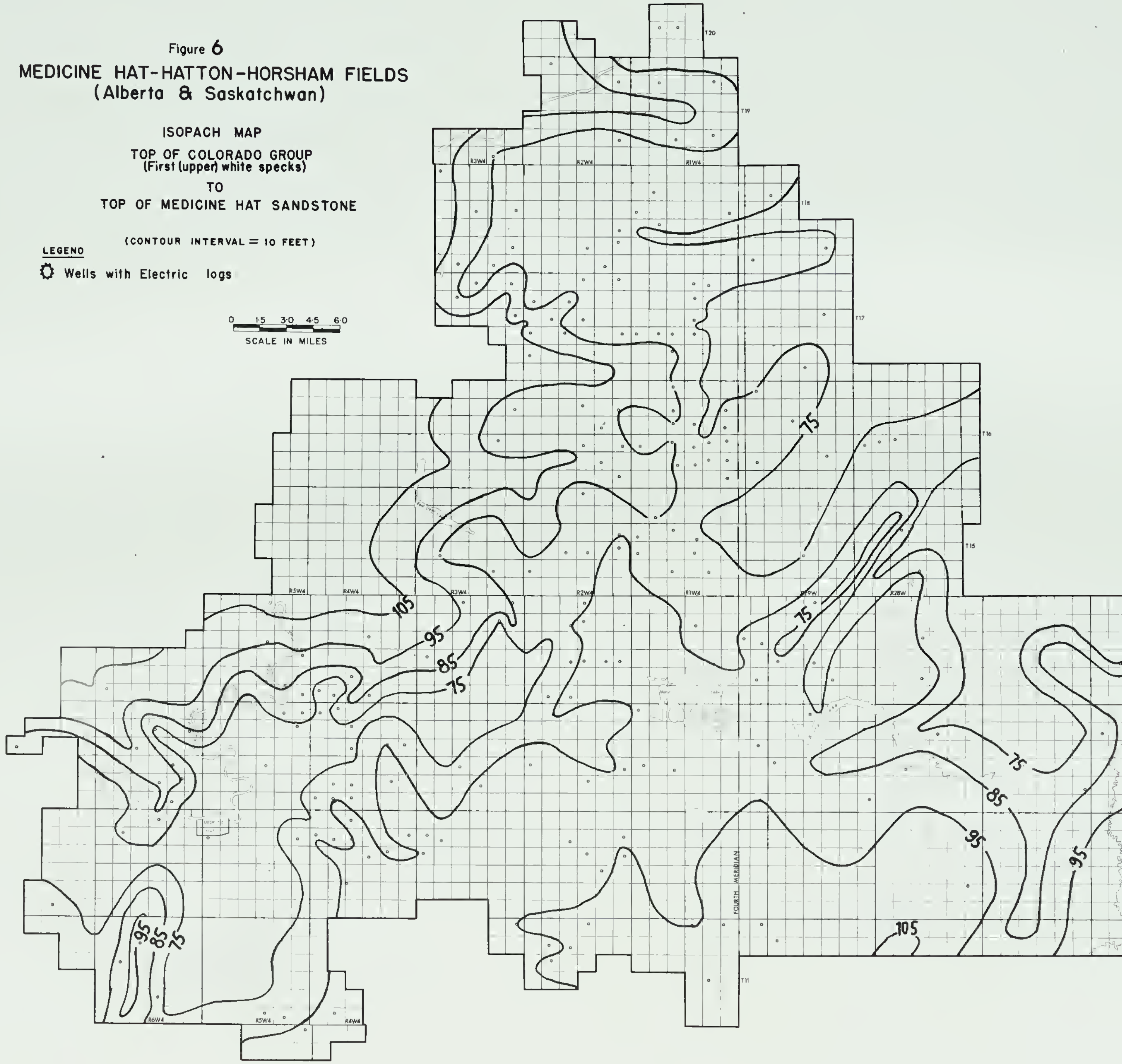


Figure 7

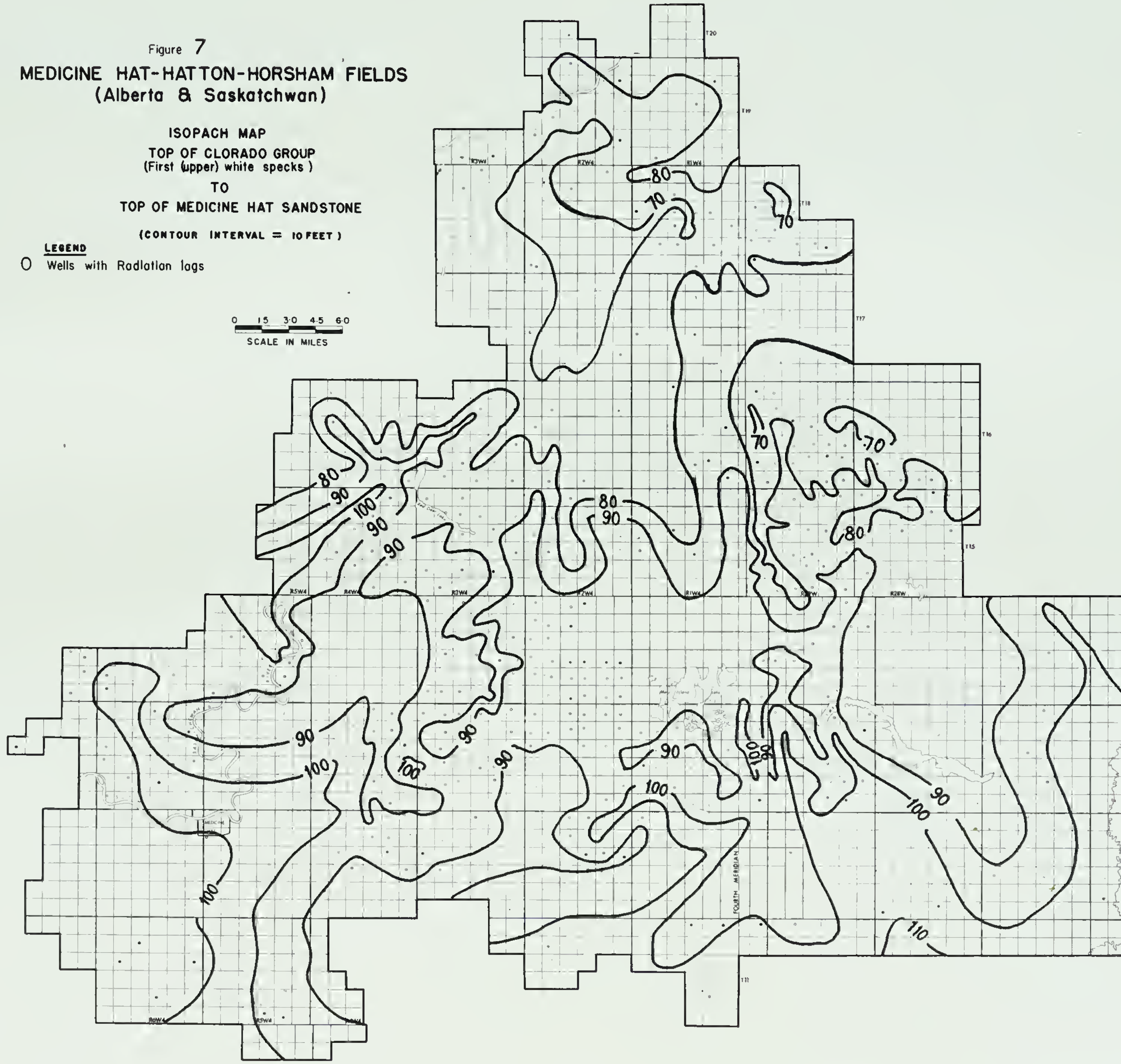
**MEDICINE HAT-HATTON-HORSHAM FIELDS**
**(Alberta & Saskatchwan)**

ISOPACH MAP
TOP OF CLORADO GROUP
(First (upper) white specks)
TO
TOP OF MEDICINE HAT SANDSTONE

(CONTOUR INTERVAL = 10 FEET)

LEGEND
O Wells with Radiation logs

0 15 30 45 60
SCALE IN MILES



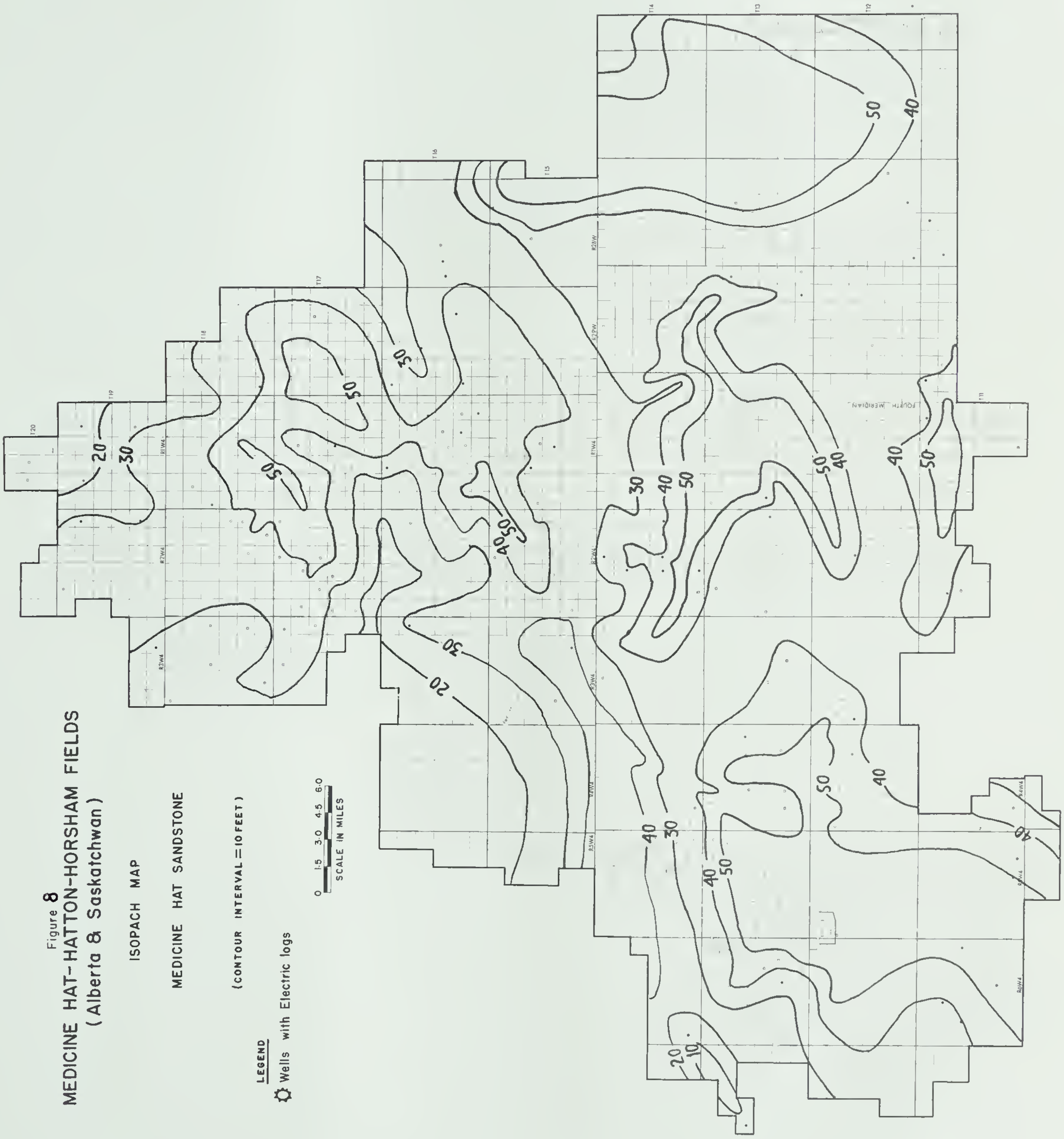


Figure 8
MEDICINE HAT-HATTON-HORSHAM FIELDS
(Alberta & Saskatchwan)

ISOPACH MAP

MEDICINE HAT SANDSTONE

(CONTOUR INTERVAL = 10 FEET)

LEGEND
Wells with Electric logs

0 1.5 3.0 4.5 6.0
SCALE IN MILES

Figure 9
MEDICINE HAT-HATTON-HORSHAM FIELDS
( Alberta & Saskatchwan )

ISOPACH MAP

MEDICINE HAT SANDSTONE

(CONTOUR INTERVAL = 10 FEET)

LEGEND

O Wells with Radiation logs

0 1.5 3.0 4.5 6.0
SCALE IN MILES

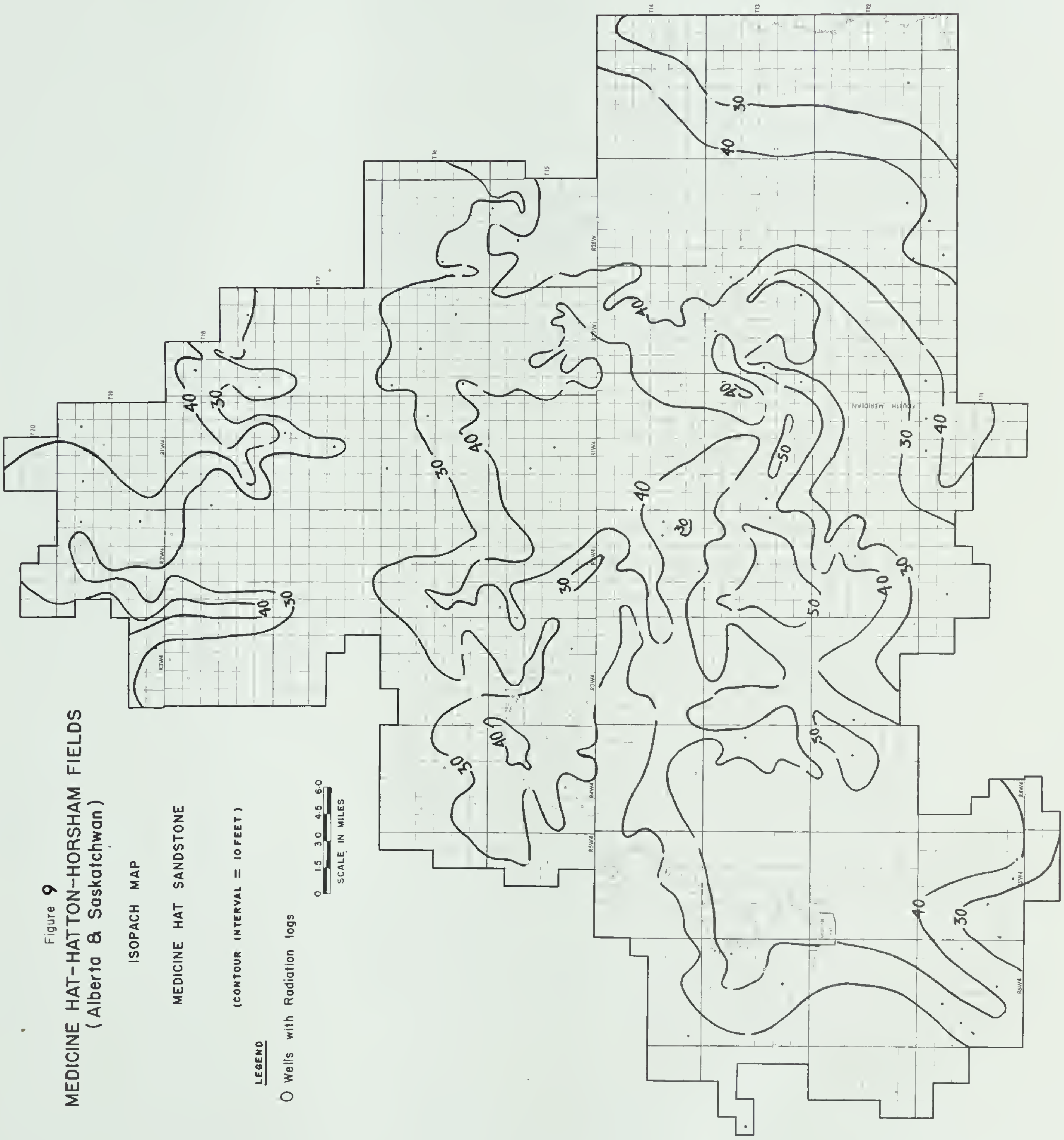


TABLE II  Chart Showing the Differences in Values Obtained from Electric and Radiation Logs for Sets A, B, C & D for 22 Wells

| No. | Well Location | SET A Isopach Top Colorado Group to Top Medicine Hat Sandstone | | | SET B Isopach Medicine Hat Sandstone | | | SET C Structural Elevation Top of Medicine Hat Sandstone | | | SET D Structural Elevation Top of Colorado Group | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Electric Log | Radiation Log | Difference | Electric Log | Radiation Log | Difference | Electric Log | Radiation Log | Difference | Electric Log | Radiation Log | Difference |
| 1 | 7-20-11-6 W4 | 88 | 94 | 6 | 40 | 36 | 4 | 1361 | 1359 | 2 | 1450 | 1449 | 1 |
| 2 | 7-28-11-6 W4 | 92 | 96 | 4 | 39 | 37 | 2 | 1344 | 1349 | 5 | 1440 | 1445 | 5 |
| 3 | 4-12-11-30 W3 | 107 | 100 | 7 | 35 | 35 | 0 | 922 | 927 | 5 | 1030 | 1027 | 3 |
| 4 | 10-36-11-30 W3 | 96, | 102 | 6 | 41 | 34 | 7 | 974 | 983 | 9 | 1073 | 1085 | 8 |
| 5 | 10-24-12-2 W4 | 97 | 91 | 6 | 42 | 36 | 6 | 1036 | 1042 | 6 | 1136 | 1133 | 3 |
| 6 | 7-26-12-4 W4 | 87 | 97 | 10 | 49 | 52 | 3 | 1170 | 1169 | 1 | 1259 | 1266 | 7 |
| 7 | 10-18-13-1 W4 | 88 | 93 | 5 | 48 | 43 | 5 | 1004 | 1008 | 4 | 1096 | 1101 | 5 |

TABLE II Continued

| No. | Well Location | SET A Isopach Top Colorado Group to Top Medicine Hat Sandstone | | | SET B Isopach Medicine Hat Sandstone | | | SET C Structural Elevation Top of Medicine Hat Sandstone | | | SET D Structural Elevation Top of Colorado Group | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Electric Log | Radiation Log | Difference | Electric Log | Radiation Log | Difference | Electric Log | Radiation Log | Difference | Electric Log | Radiation Log | Difference |
| 8 | 7-13-13-2 W4 | 88 | 90 | 2 | 25 | 43 | 18 | 1011 | 1013 | 2 | 1102 | 1103 | 1 |
| 9 | 6-25-13-6 W4 | 85 | 89 | 4 | 39 | 43 | 4 | 1224 | 1224 | 0 | 1312 | 1313 | 1 |
| 10 | 11-2-13-29 W3 | 94 | 101 | 7 | 39 | 31 | 8 | 879 | 881 | 2 | 977 | 982 | 5 |
| 11 | 6-33-13-29 W3 | 86 | 87 | 1 | 40 | 37 | 3 | 897 | 904 | 7 | 990 | 991 | 1 |
| 12 | 11-34-14-2 W4 | 91 | 98 | 7 | 38 | 30 | 8 | 1005 | 1007 | 2 | 1097 | 1105 | 8 |
| 13 | 15-15-14-27 W3 | 88 | 88 | 0 | 46 | 40 | 6 | 791 | 792 | 1 | 879 | 880 | 1 |
| 14 | 11-1-16-1 W4 | 82 | 94 | 12 | 33 | 40 | 2 | 850 | 857 | 7 | 946 | 953 | 7 |
| 15 | 11-11-16-1 W4 | 83 | 81 | 2 | 38 | 40 | 2 | 870 | 874 | 4 | 957 | 955 | 2 |
| 16 | 11-17-16-28 W3 | 78 | 70 | 8 | 27 | 36 | 9 | 854 | 862 | 8 | 932 | 932 | 0 |
| 17 | 10-7-16-29 W3 | 84 | 78 | 6 | 40 | 41 | 1 | 849 | 857 | 8 | 937 | 935 | 2 |

TABLE II Continued

| No. | Well Location | SET A Isopach Top Colorado Group to Top Medicine Hat Sandstone | | | SET B Isopach Medicine Hat Sandstone | | | SET C Structural Elevation Top of Medicine Hat Sandstone | | | SET D Structural Elevation Top of Colorado Group | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Electric Log | Radiation Log | Difference | Electric Log | Radiation Log | Difference | Electric Log | Radiation Log | Difference | Electric Log | Radiation Log | Difference |
| 18 | 10-15-17-1 W4 | 81 | 84 | 3 | 40 | 32 | 8 | 832 | 826 | 6 | 915 | 910 | 5 |
| 19 | 6-35-17-1 W4 | 80 | 78 | 2 | 40 | 39 | 1 | 841 | 845 | 4 | 926 | 923 | 3 |
| 20 | 10-6-18-29 W3 | 82 | 81 | 1 | 39 | 31 | 8 | 827 | 831 | 4 | 914 | 912 | 2 |
| 21 | 3-29-18-29 W3 | 78 | 73 | 5 | 33 | 36 | 5 | 769 | 769 | 0 | 883 | 878 | 5 |
| 22 | 6-12-19-2 W4 | 83 | 72 | 11 | 30 | 37 | 7 | 846 | 855 | 9 | 929 | 927 | 2 |
| | Average | 87 | 88 | 1 | 38 | 38 | - | 962 | 965 | 3 | 1054 | 1055 | 1 |

2. Estimates of the variability of measurable properties of the population.
3. Detection of geologically important differences between measurable properties of geological populations.
4. Estimation of degree of association (statistical correlation) and predictability among measurable properties of the population.
5. Detection and evaluation of systematic patterns of areal variation (trends) in the mappable attributes of the population.

A simple linear model represented by an equation of the form $Y = a + bX + e$ provides a very flexible device for the study of relationship among geological variables. In this equation X and Y are two random variables, a is the intercept on the Y axis, b is a constant representing the slope of the line of the equation, and e is a random error term. A computer program based on the simplified form $Y = a + bX$ and capable of producing answers to the first four of the five classes of statistical questions arising in geological studies noted above was obtained from the program library of the Computing Science Department.

The program calculates the correlation coefficient R (see Appendix E for the formulae for the calculation of Mean, Standard deviation, and correlation coefficient) which indicates how good the

quantity X is as a predictor of Y, as well as the value $100R^2$ (the percentage of variance of the population of variable Y which is accounted for by using a related variable X) and "T" values for the samples processed so that the significance of the relationship between the variables can be tested. The program is also capable of plotting any one variable against any other.

In order to determine the relationship between electrical and radiation log data, linear regression analyses were performed on each of the two isopach values and structural elevations indicated as Sets A to D on Table II. Values from electric and radiation logs were designated Y and X respectively, and consequently the expected values of a and b were zero and one. Significant deviation from these values was considered to be a function of the error term of the model. The results of these analyses are given in Tables III, IV, and V.

The values of a, b, R and $100R^2$ for sets A and B from the Table III show a significant deviation from their expected values. The $100R^2$ value shows that only 59% and 7% of the variation in the population of variable Y is accounted for by the changes in variable X for the two sets respectively and in both cases the variable X is not a good predictor of Y. These low correlation coefficients between the two variables (.77 and .27) do not justify the combination of the data represented by these variables, ie., the isopach

TABLE III Tabulated Computer Results for 22 Samples

| Map No. | Set No. | Map Designation | Mean (M) (feet) | Standard Deviation ($\sigma$) (feet) | Minimum (thickness/ Elevation) (feet) | Maximum (thickness/ Elevation) (feet) | a | b | R | $100R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | Isopach. Tp. Col. Gp. to Tp. Med. Hat Sandstone (Basis: Electric Log Data) | 87 | 7 | 78 | 107 | 38.5 | 0.55 | 0.77 | 59.2 |
| 2 | A | Isopach. Tp. Col. Gp. to Tp. Med. Hat Sandstone (Basis: Radiation Log Data) | 88 | 10 | 70 | 102 | | | | |
| 3 | B | Isopach. Med. Hat Sandstone Member (Basis: Electric Log Data) | 38 | 6 | 25 | 49 | 26.6 | 0.31 | 0.27 | 7.3 |
| 4 | B | Isopach. Med. Hat Sandstone Member (Basis: Radiation Log Data) | 37 | 5 | 30 | 52 | | | | |

TABLE III Continued

| Map No. | Set No. | Map Designation | Mean (M) (feet) | Standard Deviation ($\sigma$) (feet) | Minimum (thickness/Elevation) (feet) | Maximum (thickness/Elevation) (feet) | a | b | R | $100R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | C | Structure Contour Map Top of the Medicine Hat Sandstone Member (Basis: Electric Log Data) | 961 | 171 | 769 | 1361 | -8.3 | 1.00 | 1.00 | 100.0 |
| 6 | C | Structure Contour Map Top of the Medicine Hat Sandstone Member (Basis: Radiation Log Data) | 965 | 170 | 769 | 1359 | | | | |
| 7 | D | Structure Contour Map Top of the Colorado Group (Basis: Electric Log Data) | 1053 | 172 | 879 | 1450 | 8.7 | 0.99 | 1.00 | 100.0 |
| 8 | D | Structure Contour Map Top of the Colorado Group (Basis: Radiation Log Data) | 1054 | 173 | 878 | 1449 | | | | |

values from the two sources cannot be combined statistically.

Contrary to this, the values of a, b, R, and $100R^2$ for sets C and D are very close to their expected values. The deviation of a from the expected value of zero in these sets is insignificant in comparison to the mean values involved. The correlation coefficients of 1 and 0.99 for sets C and D respectively is ideal for the combination of the data from the two sources for a collective study. The $100R^2$ values also show that the total variation in the population of variable Y is due to the change in the variable X. On the basis of these results the structural elevations obtained from electric and radiation logs for the tops of the Medicine Hat Sandstone and Colorado Group can be combined together for the purpose of construction of structure contour maps for these surfaces.

The analysis leads to the conclusion that there are very great errors in determining the isopach values. Lack of correlation of isopach values of set A is difficult to interpret because the tops and bottoms of this interval are very closely comparable for these 22 observed values. It is, however, possible that due to the higher values of the structural elevations in the analysis as compared to the lower net values of isopach the difference may be significant in the case of isopach values. The low degree of correlation between the values of set B is attributed mainly to difficulty in determining the base of the Medicine Hat Sandstone Member. The possibility of

other disturbing factors and their respective influence on the individual values under comparison cannot be ruled out.

The analysis of data from 22 wells demonstrated the significance and usefulness of a comparison of this type. In order to further investigate the relationship between radiation and electric log data, maps of the same surface or interval drawn on the basis of these two data sources were statistically compared. Each map was covered with a 3-mile square grid, producing a total of 254 observation points at which values were obtained. Where the observation points did not fall on contour lines, the isopach or elevation values for that location were obtained by interpolating between contours. Maps from which data was collected for comparative purposes are:

Map 1 Isopach Map - Top Colorado Group to Top Medicine Hat Sandstone Member (basis: Electric log data)

Map 2 Isopach Map - Top Colorado Group to Top Medicine Hat Sandstone Member (basis: Radiation log data)

Map 3 Isopach Map - Medicine Hat Sandstone Member (basis: Electric log data)

Map 4 Isopach Map - Medicine Hat Sandstone Member (basis: Radiation log data)

Map 5 Structure Contour Map - Top of the Medicine Hat

Sandstone Member (basis: Electric log data)

Map 6 Structure Contour Map - Top of the Medicine Hat Sandstone Member (basis: Radiation log data)

Map 7 Structure Contour Map - Top of the Colorado Group (basis: Electric log data)

Map 8 Structure Contour Map - Top of the Colorado Group (basis: Radiation log data)

Map 9 Structure Contour Map - Top of the Medicine Hat Sandstone Member (basis: Electric log plus Radiation log data)

Values for the same sample grid points from each of the various sets of maps (Table II) were compared by using the computer and linear regression programme which was used in the preliminary comparison of 22 wells.

Data collected from interpretive contoured sets of maps have serious limitations and these are bound to be reflected in the results obtained when data so collected are compared. The main one of these limitations is considered to be the non-identical location of control points for the electric and radiation log data, the basis on which these contoured maps are constructed. The wells having electric type of logs have a different areal distribution from the wells

with radiation type of logs. The difference in the density of the control points for the two types of logs in different parts of the field is another factor which can give different patterns to the contoured maps. In addition to this, the maps based on electric logs have fewer control points than the maps based on radiation logs, a factor which potentially makes the latter a comparatively more reliable source. The results obtained for the 254 samples are shown in Table IV. The values of a, b, R and $100R^2$ for sets A and B in the table show that their deviation from the expected values is significantly high. The correlation coefficient (R) is very low and shows that practically no relationship exists between the values of variables X and Y. The values of $100R^2$ are 7% and 8% for sets A and B respectively, indicating that only 7% and 8% variation in the values of population Y is accounted for by the change in the values of variable X. On the basis of this it is concluded that the isopach values for the interval between the top of the Colorado Group and the top of the Medicine Hat Sandstone Member and for the thickness of the Medicine Hat Sandstone Member from the two sources cannot be combined for any subsequent geological interpretation.

The values of a, b, R and $100R^2$ for set C and set D in Table IV show a very minor deviation from their expected values and correlation coefficients (R) of 0.98 and 0.95 shows that a good relationship exists between the variables X and Y for these sets of maps.

TABLE IV Tabulated Computer Results for 254 Samples

| Map No. | Set No. | Map Designation | Mean (M) (feet) | Standard Deviation ($\sigma$) (feet) | Minimum (thickness/elevation) (feet) | Maximum (thickness/elevation) (feet) | a | b | R | $100R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | Isopach. Tp. Col. Gp. to Tp. Med. Hat Sandstone (Basis: Electric Log Data) | 87 | 11 | 55 | 112 | 62.4 | 0.27 | 0.26 | 7.0 |
| 2 | A | Isopach. Tp. Col. Gp. to Tp. Med. Hat Sandstone (Basis: Radiation Log Data) | 89 | 10 | 69 | 112 | | | | |
| 3 | B | Isopach. Med. Hat Sandstone Member (Basis: Electric Log Data) | 37 | 11 | 8 | 60 | 25.7 | 0.33 | 0.28 | 8.0 |
| 4 | B | Isopach. Med. Hat Sandstone Member (Basis: Radiation Log Data) | 34 | 9 | 14 | 53 | | | | |
| 5 | C | Structure Contour Map Top of Med. Hat Sandstone Member (Basis: Electric Log Data) | 994 | 176 | 732 | 1430 | -3.4 | 1.00 | 0.98 | 95.0 |
| 6 | C | Structure Contour Map Top of Med. Hat Sandstone Member (Basis: Radiation Log Data) | 989 | 171 | 630 | 1380 | | | | |

TABLE IV Continued

| Map No. | Set No. | Map Designation | Mean (M) (feet) | Standard Deviation ($\sigma$) (feet) | Minimum (thickness/elevation) (feet) | Maximum (thickness/elevation) (feet) | a | b | R | $100R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | D | Structure Contour Map Top of the Colorado Group (Basis: Electric Log Data) | 1087 | 181 | 765 | 1510 | 35.5 | 0.97 | 0.95 | 91.0 |
| 8 | D | Structure Contour Map Top of the Colorado Group (Basis: Radiation Log Data) | 1082 | 178 | 800 | 1473 | | | | |
| 9 | E | Structure Contour Map Top of the Medicine Hat Sandstone Member (Basis: Electric Log plus Radiation Log Data) | 988 | 172 | 710 | 1426 | -13.4 | 1.00 | 0.99 | 98.0 |
| 5 | E | Structure Contour Map Top of the Medicine Hat Sandstone Member (Basis: Electric Log Data) | 994 | 176 | 732 | 1430 | | | | |

TABLE IV Continued

| Map No. | Set No. | Map Designation | Mean (M) (feet) | Standard Deviation (σ) (feet) | Minimum (thickness/elevation) (feet) | Maximum (thickness/elevation) (feet) | a | b | R | $100R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 9 | | Structure Contour Map Top of the Medicine Hat Sandstone Member (Basis: Electric Log plus Radiation Log Data) | 988 | 172 | 710 | 1426 | 19.8 | 0.98 | 0.98 | 97.0 |
| 6 | F | Structure Contour Map Top of the Medicine Hat Sandstone Member (Basis: Radiation Log Data) | 989 | 170 | 630 | 1380 | | | | |

The values of $100R^2$ indicate that 95% and 91% of the variation in populations of variable Y is due to the change in variable X. Data pertaining to the structural elevations at the top of the Medicine Hat Sandstone and the Colorado Group from the two log sources can be combined and collectively studied and conclusions can be drawn.

The values of a, b, R and $100R^2$ for the sets E and F in Table IV show that deviation from their expected values is very minor, and the existence of a close relationship between variables X and Y is demonstrated by the high values of R. The $100R^2$ values for these sets show that 98% and 97% variation in the values of population Y is accounted for by the change in variable X and that variable X is a very good predictor of variable Y. The results pertaining to sets E and F also demonstrate that maps constructed with the combined data from the two sources carry very close relationships with maps constructed from data from each source independently.

The results of statistical analysis of 254 estimated values from the electric log-and radiation log-based isopach and structure contour maps are in conformity with the results obtained by analyzing the observed values from 22 wells. The isopach values do not correlate, but structural elevations show a very high degree of correlation between the data obtained from the two sources. Structural data can be combined and a map based on these combined data

can be constructed and used in conjunction with maps based on either data.

A comparison of the results of Table III and Table IV pertaining to sets A, B, C, and D shows that the parameters a, b, R and $100R^2$ have higher values for the observed samples from 22 wells than the estimated 254 samples collected from the maps. The lower values of parameters in the latter case, may be attributed to errors inherent in the collection of data from interpretive contour maps.

In order to determine the effect of density of control points on the results, the data from the central part of the fields lying between Townships 12 and 16 of the area of Figure 2 containing the maximum number of wells and having 186 of the 254 observation points were similarly processed and the results for these 186 samples are shown in Table V.

The results shown in Table V show no change, or a slight worsening of the relationship as compared with results in Table IV, except for set B where the selection of data from the central part of the area only seems to have effected an improvement in the relationship.

A comparison of the values shown in Tables III and V shows that the relationship between the isopach values for the Medicine Hat Sandstone Member (set B) shows a significant improvement when the data from 186 estimated values is processed and results obtained

TABLE V Tabulated Computer Results for 186 Samples

| Map No. | Set No. | Map Designation | Mean (M) (feet) | Standard Deviation ($\sigma$) (feet) | Minimum (thickness/elevation) (feet) | Maximum (thickness/elevation) (feet) | a | b | R | $100R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | Isopach. Tp. Col. Gp. to Tp. Med. Hat Sandstone (Basis: Electric Log Data) | 88 | 11 | 55 | 112 | 77.0 | 0.11 | 0.09 | 0.8 |
| 2 | A | Isopach. Tp. Col. Gp. to Tp. Med. Hat Sandstone (Basis: Radiation Log Data) | 91 | 8 | 70 | 110 | | | | |
| 3 | B | Isopach. Medicine Hat Sandstone Member (Basis: Electric Log Data) | 38 | 12 | 8 | 60 | 19.5 | 0.51 | 0.42 | 18.0 |
| 4 | B | Isopach. Medicine Hat Sandstone Member (Basis: Radiation Log Data) | 35 | 9 | 14 | 53 | | | | |
| 5 | C | Structure Contour Map Top of the Medicine Hat Sandstone Member (Basis: Electric Log Data) | 1017 | 160 | 732 | 1375 | 33.4 | 0.97 | 0.97 | 94.0 |
| 6 | C | Structure Contour Map Top of the Medicine Hat Sandstone Member (Basis: Radiation Log Data) | 1013 | 160 | 630 | 1350 | | | | |

TABLE V Continued

| Map No. | Set No. | Map Designation | Mean (M) (feet) | Standard Deviation (σ) (feet) | Minimum (thickness/elevation) (feet) | Maximum (thickness/elevation) (feet) | a | b | R | $100R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | | Structure Contour Map Top of the Colorado Group (Basis: Electric Log Data) | 1110 | 168 | 765 | 1475 | 45.8 | 0.96 | 0.94 | 88.0 |
| | D | | | | | | | | | |
| 8 | | Structure Contour Map Top of the Colorado Group (Basis: Radiation Log Data) | 1111 | 165 | 810 | 1473 | | | | |
| 9 | | Structure Contour Map Top of the Medicine Hat Sandstone Member (Basis: Electric plus Radiation Log Data) | 1010 | 157 | 710 | 1348 | -3.2 | 1.0 | 0.99 | 97.0 |
| | E | | | | | | | | | |
| 5 | | Structure Contour Map Top of the Medicine Hat Sandstone Member (Basis: Electric Log Data) | 1017 | 160 | 732 | 1375 | | | | |
| 9 | | Structure Contour Map Top of the Medicine Hat Sandstone Member (Basis: Electric plus Radiation Log Data) | 1010 | 157 | 710 | 1348 | -0.8 | 1.0 | 0.98 | 97.0 |
| | F | | | | | | | | | |

TABLE V Continued

| Map No. | Set No. | Map Designation | Mean (M) (feet) | Standard Deviation (σ) (feet) | Minimum (thickness/elevation) (feet) | Maximum (thickness/elevation) (feet) | a | b | R | $100R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | F | Structure Contour Map Top of the Medicine Hat Sandstone Member (Basis: Radiation Log Data) | 1013 | 160 | 630 | 1350 | | | | |

compared with data from the 22 wells. This improvement in the relationship is explained by the fact that the isopach values obtained from the 22 wells are randomly scattered all over the area whereas the 186 thickness values were obtained by systematically sampling the area with a relatively better sand body development.

In addition to the statistical analyses discussed above, a similar comparison was made of the net sand thickness (sand isolith) of the Medicine Hat Sandstone Member as derived from 5 millivolt and 10 millivolt spontaneous potential deflections on 202 electric logs as described earlier. A regression was also performed, comparing the structural elevation of the top of the Medicine Hat Sandstone with that of the top of the Colorado Group in these same 202 wells. The results obtained are shown in Table VI.

The values of parameters a, b, R and $100R^2$ for the sand isoliths in Table VI are close to the values expected if the quantities were identical. The value of $100R^2$ indicates that 70% of the variation in the value of sand isolith calculated from 10 millivolt spontaneous potential deflection is accounted for by the change in the value of sand isolith calculated from 5 millivolt spontaneous potential deflection. The mean value of net thickness of sand is significantly higher when a 5 millivolt spontaneous potential deflection is used as compared to a 10 millivolt deflection.

When structural elevations of the top of the Colorado Group

TABLE VI Tabulated Computer Results for 202 Electric Logs Having

Sand Isolith (5 mv and 10 mv deflection on S.P. curve)

| Map No. | Set No. | Quantity | Mean M (feet) | Standard Deviation $\sigma$ (feet) | Minimum (thickness) (feet) | Maximum (thickness) (feet) | a | b | R | $100R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 11 | A | Net Sand Thickness (Sand Isolith) (Basis: 10 millivolt S.P. Deflection) | 11 | 11 | 0 | 55 | -6.0 | 0.84 | 0.84 | 70.0 |
| 12 | | Net Sand Thickness (Sand Isolith) (Basis: 5 millivolt S.P. Deflection) | 20 | 11 | 2 | 55 | | | | |
| 5 | B | Structural Elevation Top of the Medicine Hat Sandstone Member (Basis: 202 Electric Logs) | 1001 | 163 | 606 | 1404 | 92.4 | 0.99 | 0.99 | 99.0 |
| 7 | | Structure Elevation Top of the Colorado Group (Basis: 202 Electric Logs) | 1092 | 163 | 717 | 1506 | | | | |

were compared with structural elevations of the top of the Medicine Hat Sandstone Member a very close correlation was obtained. The intercept a in this case is the average thickness of the stratigraphic section between these two markers. The regression indicates that the top of the Medicine Hat Sandstone Member and the top of the Colorado Group are approximately parallel.

A regression plot between the sand isolith and the structural elevation on top of the Medicine Hat Sandstone Member showed that higher sand isolith values are found in areas with highest elevations. This relationship is also shown by examination of the contoured sand isolith map and structural contour map for the top of the Medicine Hat Sandstone Member.

The regression plots between the components discussed above constitute Appendix D.

## Discussion of Selected Maps

The foregoing statistical analyses have shown that only structural elevation values convey a reliable geological picture. Either set of sand isolith values is probably equally reliable, although the 5 millivolt data provides a more optimistic picture, as indicated by the difference in mean values. As a consequence, the structural contour maps for the top of the Medicine Hat Sandstone Member (Fig. 10) and the top of the Colorado Group (Fig. 11) utilizing combined data from the two sources, and the sand isolith map constructed

Figure 10

MEDICINE HAT-HATTON-HORSHAM FIELDS
(Alberta & Saskatchewan)

STRUCTURE CONTOUR MAP ON
TOP OF MEDICINE HAT SANDSTONE
(CONTOUR INTERVAL=25FEET)

LEGEND
○ Wells with Radiation logs.
☼ Wells with Electric logs.
✸ Wells with both types of logs.

0 15 30 45 60
SCALE IN MILES

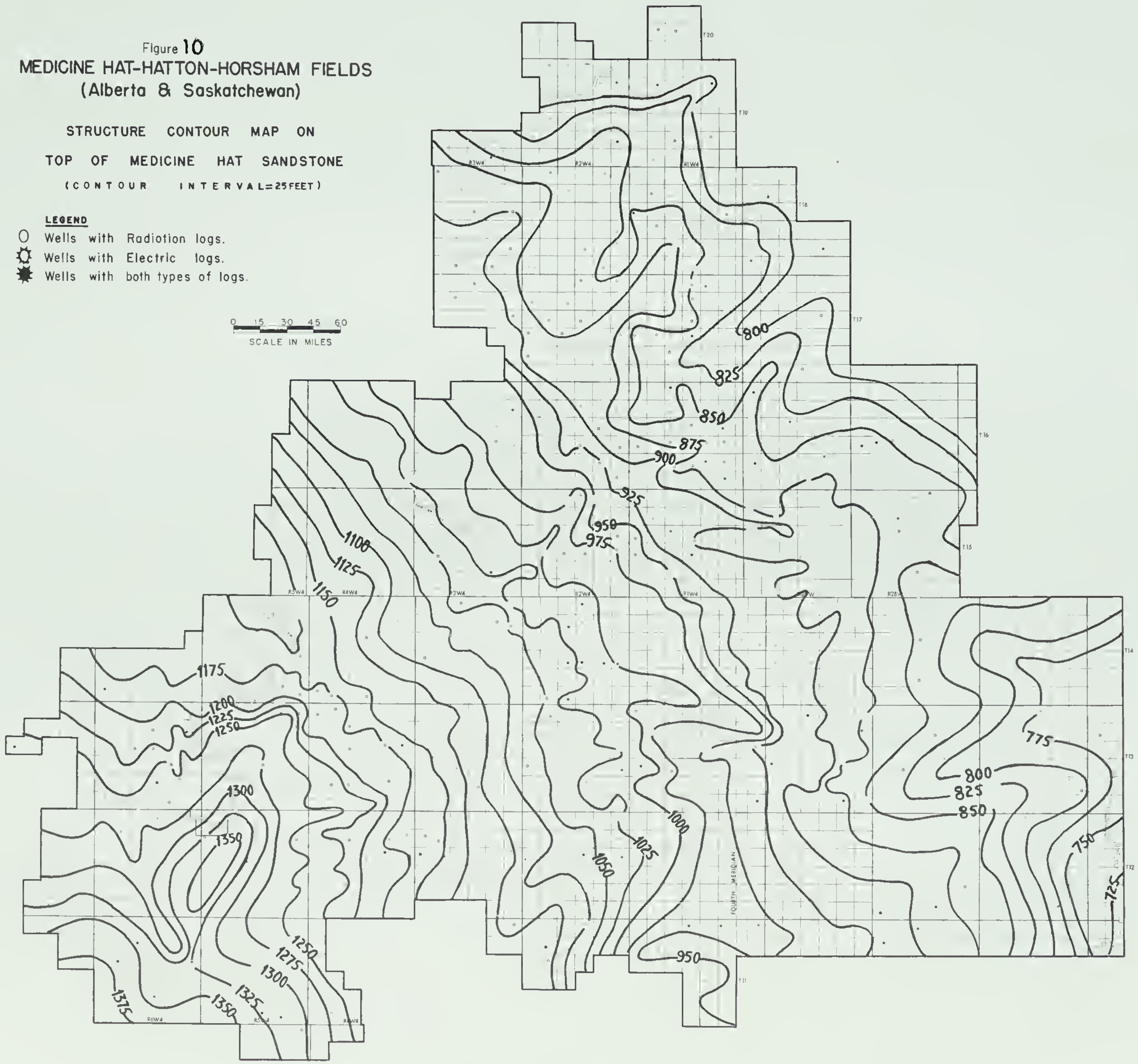


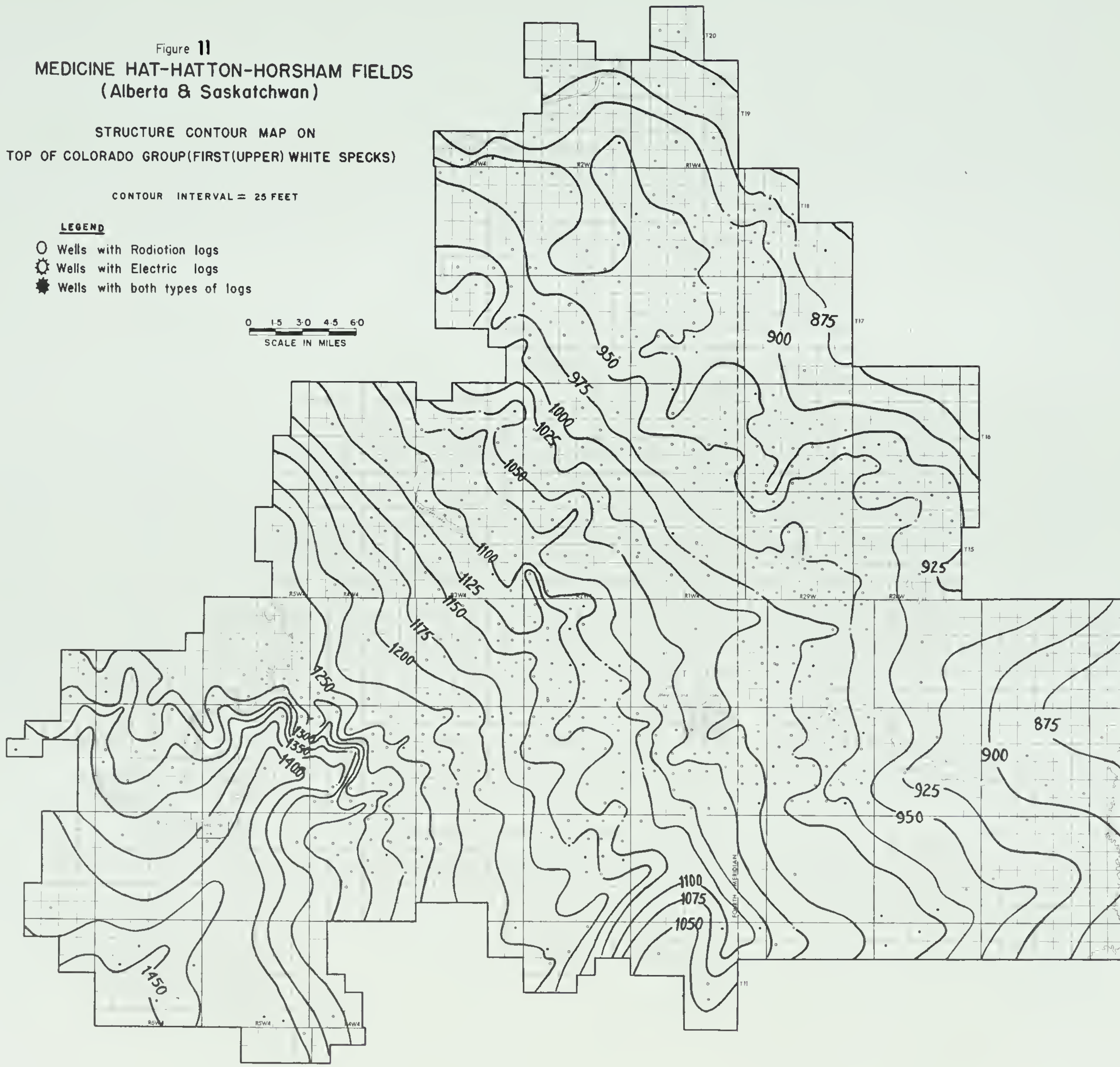
Figure 11
MEDICINE HAT-HATTON-HORSHAM FIELDS
(Alberta & Saskatchwan)

STRUCTURE CONTOUR MAP ON
TOP OF COLORADO GROUP (FIRST (UPPER) WHITE SPECKS)

CONTOUR INTERVAL = 25 FEET

LEGEND
- Wells with Rodiotion logs
- Wells with Electric logs
- Wells with both types of logs

0 1.5 3.0 4.5 6.0
SCALE IN MILES



with 5 millivolt spontaneous potential deflection values were selected for detailed discussion. The significant features shown by each of these maps are described below.

I - Structure Contour Map on the Top of the Medicine Hat Sandstone Member (basis: Electric log plus Radiation log data)

The entire area of Figure 10 shows a homoclinal structure with a northeastward dip having local small-scale features, such as the northeast-plunging assymetrical anticline in the southwestern part of the field, which has been termed the Medicine Hat Structure by Meyboom (1960). This feature appears to be the only closed structure in the area.

II - Structure Contour Map on the Top of the Colorado Group (basis: Electric log plus Radiation log data)

The contour pattern of this map (Figure 11) is similar to that of the structure contour map for the top of the Medicine Hat Sandstone Member (Fig. 10) as might be expected on the basis of the data in Table VI. The main difference is the lack of closure on the Medicine Hat Structure at this horizon. Small-scale local variations may be explained by a consideration of the limitations inherent in the construction of contour maps from a given set of data.

III - Sand Isolith Map of the Medicine Hat Sandstone Member

(basis: 5 millivolt spontaneous potential deflection)

This map (Fig. 12) shows that the sand thins in all directions from the centre of the field. The thickest sand isolith zone, inside the 50 foot contour is associated with the structurally high area in the southwest, but the low contour values in the extreme southwestern corner of the map suggest pinching out in that direction. The distribution of the thicker sandy zones, however, does not appear to follow any particular trend in the area of study. The average thickness of net sand in the Medicine Hat Sandstone Member is 20 feet (Table VI).

A visual comparison of the isopach maps for the Medicine Hat Sandstone Member (Figs. 8 and 9) with the isolith map (Fig. 12) shows that a general relationship seems to exist between the contoured patterns except that the area with low net sandstone thickness shown by Fig. 12 in Township 13, Ranges 1 and 2, West of the Fourth Meridian has no corresponding thin zone on the isopach maps (Figs. 8 and 9).

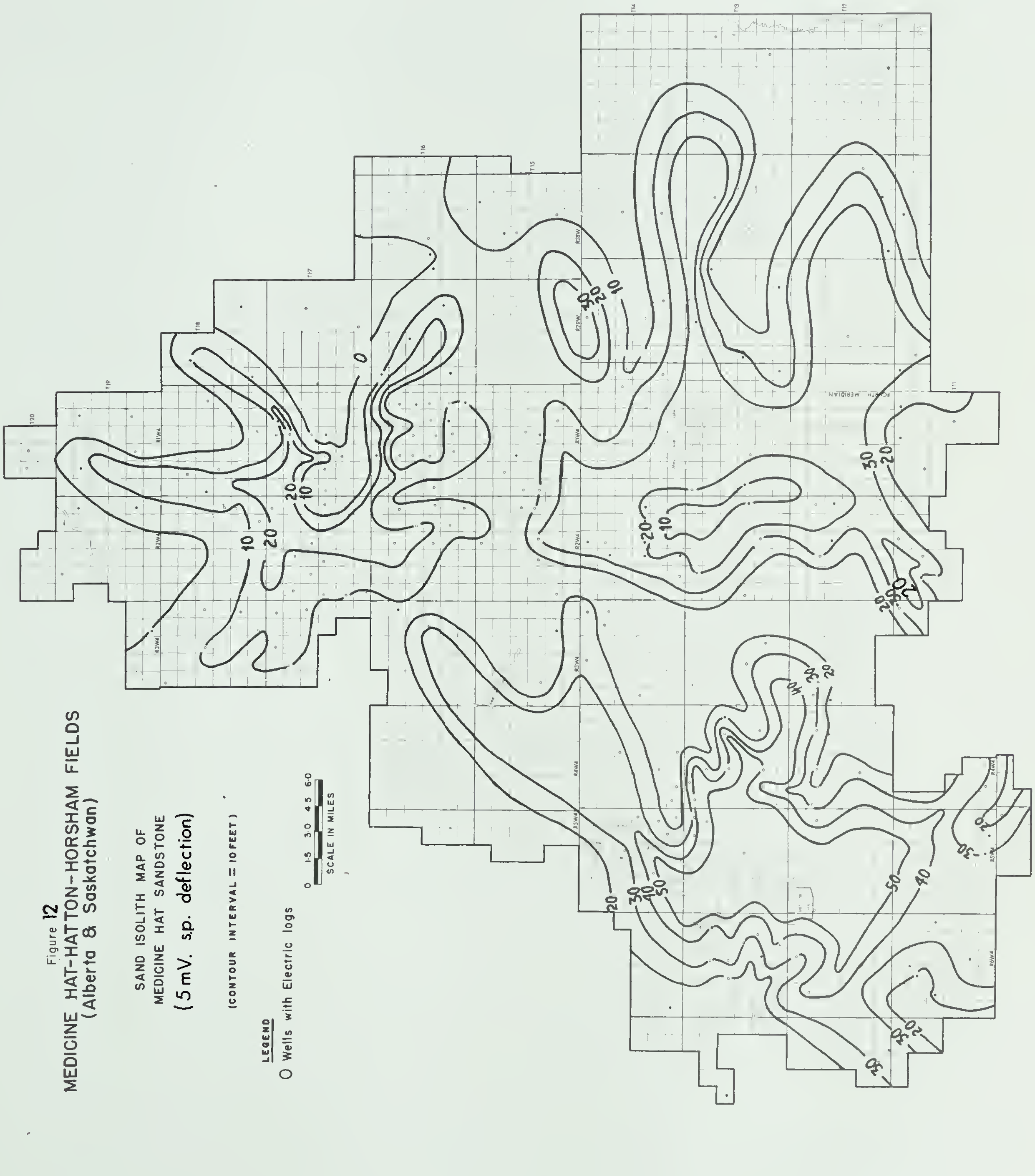


Figure 12
MEDICINE HAT-HATTON-HORSHAM FIELDS
(Alberta & Saskatchwan)

SAND ISOLITH MAP OF
MEDICINE HAT SANDSTONE
(5 mV. s.p. deflection)

(CONTOUR INTERVAL = 10 FEET)

0 1.5 3.0 4.5 6.0
SCALE IN MILES

LEGEND
O Wells with Electric logs

# CHAPTER FOUR - COMPOSITION OF THE MEDICINE HAT SANDSTONE MEMBER

## Petrography of Thin Sections

Thin Section Preparation: Sandstones of the Medicine Hat Member are very friable, loosely-compacted rocks with the compactness generally dependent upon the amount of cement present. Calcite-cemented sandstone is comparatively harder than sandstone bound with clay matrix. In order to get the thin sections from these rocks it was necessary to impregnate the samples before cutting. The following procedure was adopted for the impregnation of the samples.

1" x 1" blocks of the core samples were put in separate containers under vacuum for 20 minutes to remove air from the interstitial pores. After this time, the resin liquid, a mixture of "Castolite", "Castolite Thinner", and "Castolite Hardner" mixed in a ratio of 25:5:1 was poured into the sample containers still under vacuum, until the samples were covered with resin. The samples were then removed from the vacuum, left at room temperature for 24 hours, and then placed in an oven for 24 hours at a temperature of 70$^{\circ}$F. After this the samples were cooled at room temperature. The impregnated samples were cut and mounted according to the normal procedure, using Lakeside 70 as a mounting medium.

Staining for Feldspar: Due to the fine grain size of the rocks under study, it was generally not possible to optically differentiate between quartz and feldspar. Staining techniques for qualitative and quantitative determination of potassium feldspar and plagioclase, therefore, were tried as a useful alternative. First, an effort was made to stain thinly cut slabs of the sandstone, but the simultaneous staining of matrix, detrital clays and other constituents in the sandstone presented a considerable problem in obtaining the desired results, and hence staining of twenty uncovered thin sections from the Medicine Hat Field was carried out according to the methods described by Hayes and Klugman (1959).

Another limitation of the staining technique which was experienced in this case was the overlapping of the staining colours for potassium feldspar and plagioclase when both sodium cobaltinitrite and erythrosin B solutions were used. This overlapping of colours makes qualitative as well as quantitative determinations of these two types of feldspars impossible and unreliable. To avoid this complication and obtain the desired results three thin sections from different parts of the Medicine Hat Field were stained for the detection of plagioclase. The results of the staining tests on these thin sections showed that the sandstone contains only traces of plagioclase. On the basis of these results staining for plagioclase was abandoned and all twenty thin sections were stained for potassium

feldspar only. The staining showed that potassium feldspar was comparatively abundant in all the thin sections.

Essential Components: The Medicine Hat Sandstone is composed of quartz, sedimentary rock fragments (chert, shale) and feldspar (dominantly potassium feldspar) as essential components and pyrite, carbonates, carbonaceous (coal) fragments, zircon, apatite, biotite, tourmaline, garnet and hornblende as accessory constituents. Matrix, composed of clays and very fine silts and calcite cement are the common materials which bind the grains of the rock together.

In some thin sections both types of binding materials are present simultaneously with a distinct distribution. The calcite is authigenic and seems to replace the matrix in the sandstone.

The sandstone is very fine to fine-grained (Plate III, Nos. 2 and 5) with size range between 0.05 mm. and 1.75 mm. (average 0.1 mm.) and grains are generally sub-angular to sub-rounded (Plate III, No. 4) with moderate to good sorting (Plate III, No. 3). Bedding is horizontal to somewhat oblique, and graded bedding was observed in some of the thin sections. The grains are not closely packed due to the generally significant matrix content. Streaks of shaly material and matrix (clay to silt) of variable thickness are present in the thin sections (Plate I, Nos. 3, 5, and 6). In some cases the matrix components are more abundant than the coarser

components (Plate I, Nos. 2 and 4).

1. Quartz: Common quartz (Lerbekmo, 1963) is the most abundant mineral, making up 62% to 76% of the rock with an average of 68% of the total rock components. Size of the grains varies from coarse silt to fine sand, with an average size of 0.1 mm. No significant size variation was observed from one part of the area to another. The grains are often elongated, angular to sub-rounded with most being sub-angular to sub-rounded. Grains are generally unstrained but a small percentage of quartz grains do show undulatory extinction. Inclusions are generally zircon and mica (Plate III, No. 1). Fractured quartz grains are present (Plate I, No. 1) but polycrystalline quartz grains are rare and no overgrowths were observed. Generally the quartz has a fresh appearance.

The morphologic features and appearance of the quartz gains suggest that it may have been derived from igneous or sedimentary rocks.

2. Rock Fragments: Sedimentary rock fragments (chert, shale and carbonates) constitute the second most abundant type of detrital grains after quartz in the sandstone. They are present with a range of 6% to 21% (average 13%) of the total rock composition. Although there is some variation in the relative

percentages of chert and shale in the total quantity of the rock fragments, chert seems to be the major constituent. The chert is generally colourless to light reddish and sub-rounded. It seems to have an even distribution, making up 1% to 12% of the rock (average 6%). Shale fragments are generally of fine sand size and are generally light to dark reddish brown (Plate III, No. 6).

3. Feldspar: Potassium feldspar is dominant and composes a trace to 9% of the rock with an average of 4%. Plagioclase ranges up to 1% in the overall composition of the rock.

Both varieties are present as fresh, unaltered to slightly altered, clear, sub-angular to sub-rounded grains with an average size of 0.1 mm. They are seen to be uniformly distributed in the rock. No overgrowths were seen. The fresh appearance of feldspar also leads to the conclusion that it is derived either from an igneous rock or by the reworking of the bentonites present in the enclosing shale.

Other Components:

1. Carbonates: Very high birefringence makes this mineral an easily distinguishable detrital constituent of the sandstone. Carbonate grains generally sub-angular to sub-rounded make up 1% to 7% (average 3%) of the sandstone, and are

fairly uniformly distributed.

2. Carbonaceous Fragments: In the megascopic study of the Medicine Hat Sandstone, flakes of coaly material are obvious. Under the microscope the carbonaceous fragments are distinguished from other dark consituents by their dull black appearance under reflected light. It constitutes 2% to 13% (average 5%) of the total composition of the sandstone. Some of the interfragmental voids are filled by carbonaceous material. The distribution of this material from one location to another in the area under study is sporadic.

3. Collophane: (Plate II, No. 3) Elongated, tabular shaped, reddish brown grains with distinct structures are termed collophane. They constitute up to 5% (average 2%) of the total rock. Such grains are generally isotropic but occasionally show very weak birefringence. They are sporadically distributed in the thin sections with samples from the central part of the field being richest in this material.

4. Matrix: The relative abundance of very fine grained shaly to silty material having a diameter less than 0.02 mm. has been mentioned earlier. The ratio of matrix to the framework constituents of the sandstone was found to be greatly variable from one sample to another. Therefore the quantity of matrix was visually estimated rather than counted. It is present in the

range of 3% to 30% of the total rock composition.

Matrix is the dominant binding material for the coarser detrital components of the sandstone and is replaced by authigenic calcite in some cases. Some thin sections show the presence of matrix and calcite as the binding materials with sporadic to distinct areal distribution.

The clay size constituents of the matrix were determined to be chlorite (?) kaolinite, illite and very fine quartz by X-ray analysis.

5. Cement: Calcite is the only cement which could be detected from the thin section study. This is generally patchy in nature and wherever present is a replacement of the matrix and finer grained constituents. Small elongated lenses of calcite cement in the rock also show that it has replaced the streaks of matrix (Plate II, No. 2). Thin sections with calcite cement were found to have good sorting and very little matrix. The patchy calcite may be the product of leaching of the calcareous material (fossil fragments, shells, organic remains, etc.) which are present in the enclosing shale.

Calcite cement was not quantitatively determined by grain counting methods. Instead a visual estimation of the relative quantity of calcite present in a thin section was made. It was observed to form 15% to 40% of the sandstone wherever it is present as a cementing material. Its areal distribution in the sandstone is

EXPLANATIONS

PLATE I

Thin Section photomicrographs of Medicine Hat Sandstones

Figure 1 Fractured quartz and detrital calcite grains in matrix rich sandstone (7-6-18-2 W4, 1669 ft.) plane polarized light, X 40.

Figure 2 Quartz and dark coloured rock fragments bound by matrix (6-29-15-1 W4, 1810 ft.), plane polarized light, X 40.

Figure 3 Sandstone with shale intercalations (7-6-18-2 W4, 1674 ft.), plane polarized light, X 25.

Figure 4 Sandstone with dominant proportion of matrix (10-17-13-3 W4, 1428 ft.), plane polarized light, X 40.

Figure 5 Poorly sorted sandstone with streaks and laminations of shale (10-17-13-3 W4, 1428 ft.), plane polarized light, X 40.

Figure 6 Sandstone and shale contact zone (6-17-13-1 W4, 1410 ft.), plane polarized light, X 40.

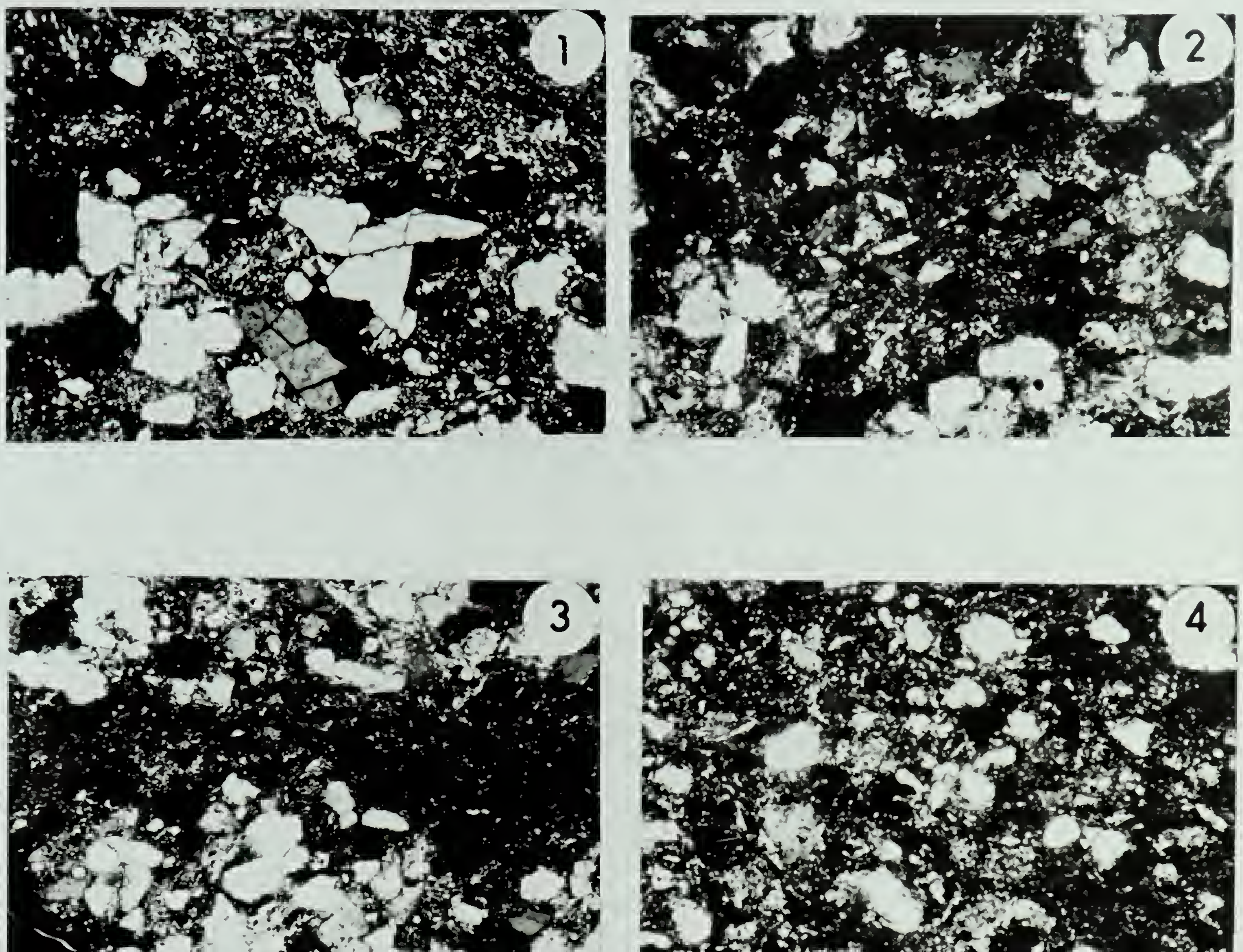



PLATE I.

## EXPLANATIONS

## PLATE II

Thin section photomicrographs of Medicine Hat sandstones.

Figure 1 Well cemented patch of sandstone with calcite cement (6-34-13-6 W4, 1250 ft.), plane polarized light, X 40.

Figure 2 Vein of calcite cement replacing matrix (7-6-18-2 W4, 1669 ft.), plane polarized light, X 40.

Figure 3 Tabular Collophane fragment (11-1-16-1 W4, 1884 ft.), plane polarized light, X 40.

Figure 4 Well sorted sandstone from the main part of the reservoir (6-13-14-2 W4, 1437 ft.), plane polarized light, X 40.

Figure 5 Poorly sorted sandstone with calcite cement (6-29-13-2 W4, 1368 ft.), plane polarized light, X 40.

Figure 6 Poorly sorted argillaceous sandstone with matrix binding material (10-17-13-3 W4, 1405 ft.), plane polarized light, X 40.

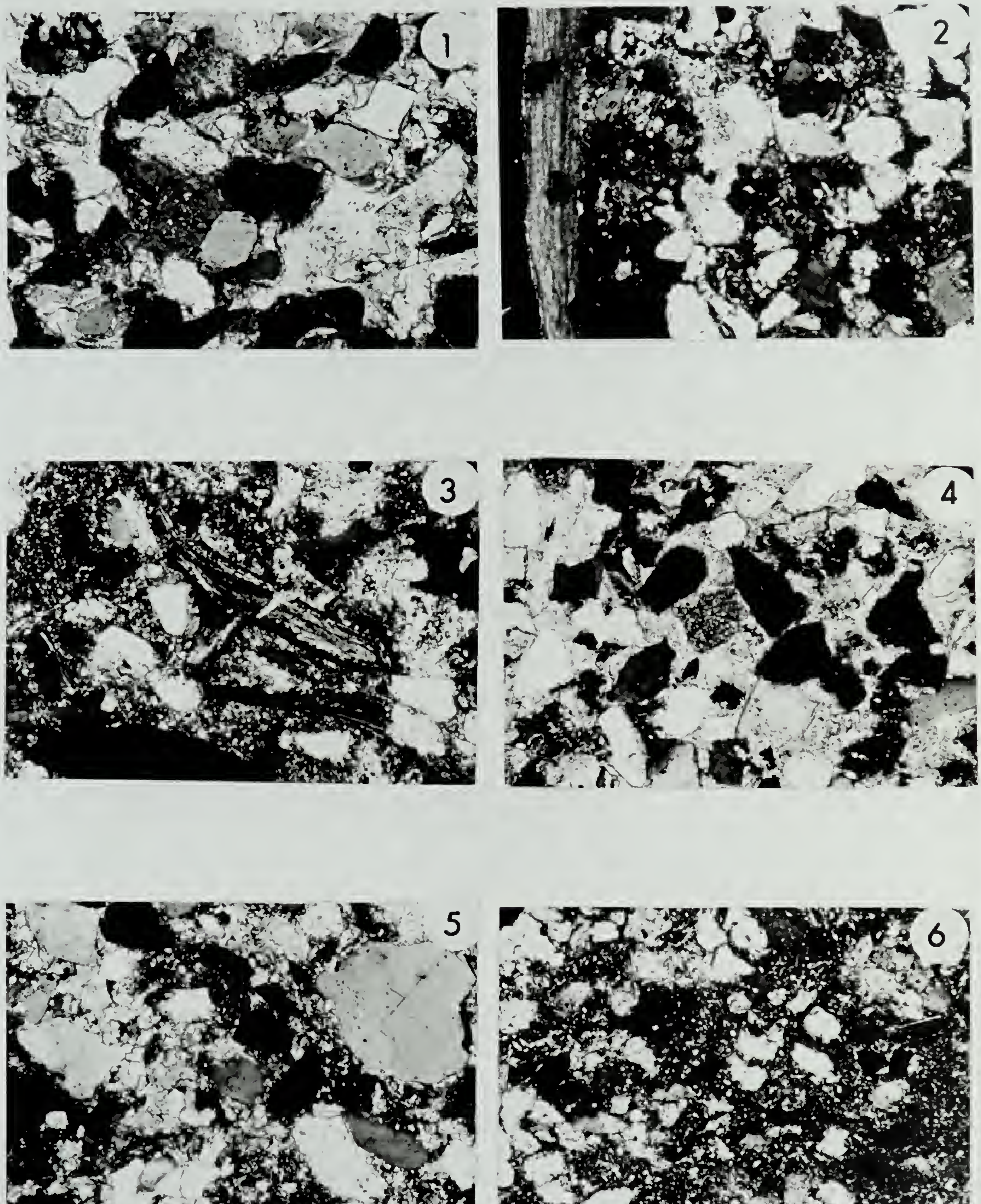



PLATE II.

## EXPLANATIONS

## PLATE III

Thin section photomicrographs of Medicine Hat Sandstones.

Figure 1 Zircon inclusions in quartz; stained pottassium feldspar (11-21-16-1 W4, 1884 ft.), plane polarized light, X 64.

Figure 2 Twinned albite and stained pottassium feldspar grains in a moderately to well sorted sandstone (11-27-16-2 W4, 1817.6 ft.), plane polarized light, X 40.

Figure 3 Well sorted and well indurated sandstone with dark coloured rock fragments (11-27-16-2 W4, 1817.6 ft.), plane polarized light, X 40.

Figure 4 Sandstone with matrix as binding material and one microcline feldspar grain (6-34-13-6 W4, 1235 ft.), plane polarized light, X 40.

Figure 5 Subangular to subrounded, poorly to moderately sorted sandstone (7-20-11-6 W4, 1065 ft.), plane polarized light, X 40.

Figure 6 Sandstone with abundant dark carbonaceous shale fragments (6-13-14-2 W4, 1437 ft.), plane polarized light, X 40.

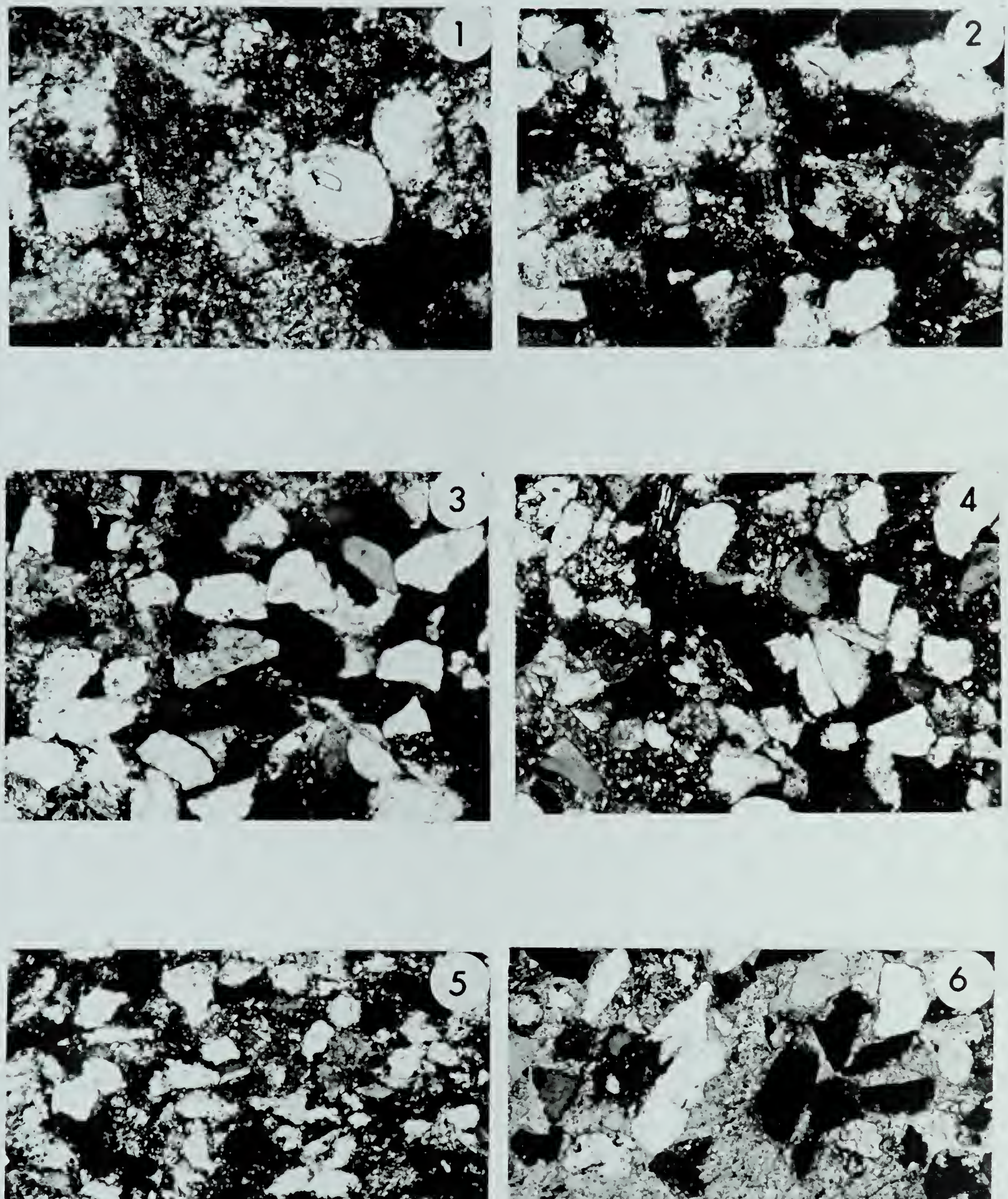



PLATE III.

probably sporadic.

Porosity: Porosity in the sandstone appears to be variable, with calcite cement as an effective factor in reducing the original porosity. Sandstones with high matrix content seem to have comparatively higher porosity. Core analyses from 10 wells from different parts of the area (when studied) show that (the sandstone from) the main part of the sandstone body (central part of the Medicine Hat Field) has the highest porosity. Porosity ranges from 1% to 33%, including variations in the porosity values for sandstone from different levels in the same well. Table VII shows average weighted porosity values for the sandy zone of the 10 wells.

The percentages of all the constitutents of Medicine Hat Sandstone and of the essential components only, recalculated to 100 percent are shown in Table VIII for the nine sandstone samples for which grain counting was carried out.

Classification of Sandstone: Pei-Yuan Chen's (1968) classification of sandstone was used in the present study. This scheme of classification, which is the most recent addition to a long list of sandstone classifications, uses the conventional ternary diagram, with quartz, feldspar and rock fragments at the poles. The quartz pole in this scheme includes all types of composite mega-quartz grains larger than 0.02 mm. but not the chert which is included

TABLE VII The average Porosity Valuesfor Medicine Hat Sandstone from 10 Wells

(Basis:- Core Analysis by Core Laboratories Canada, Calgary, Alberta)

| No. | Well Location | Minimum Porosity (%) | Maximum Porosity (%) | Footage Analyzed | Weighted Average Porosity (%) |
|---|---|---|---|---|---|
| 1 | 10-17-13-3 W4 | 6.7 | 33.2 | 28.0 | 29.0 |
| 2 | 11-24-13-4 W4 | 15.4 | 33.2 | 26.0 | 24.0 |
| 3 | 6-13-14-2 W4 | 5.8 | 33.0 | 23.0 | 22.0 |
| 4 | 10-18-14-3 W4 | 10.8 | 31.6 | 30.0 | 23.0 |
| 5 | 10-28-15-3 W4 | 10.0 | 28.1 | 22.0 | 16.0 |
| 6 | 11-17-16-28 W3 | 15.7 | 28.3 | 27.0 | 21.0 |
| 7 | 6-1-16-29 W3 | 17.0 | 29.7 | 16.0 | 25.0 |
| 8 | 11-28-17-3 W4 | 11.0 | 18.5 | 4.6 | 27.0 |
| 9 | 10-35-18-2 W4 | 8.1 | 22.1 | 16.0 | 21.0 |
| 10 | 10-6-18-29 W3 | 12.5 | 20.4 | 26.0 | 15.0 |

TABLE VIII Composition[1] of Medicine Hat Sandstones

(Values rounded to nearest whole percent)

| Sample No. | 11-6 | 12-4 | 13-3 | 14-2 | 15-2 | 16-1 | 17-2 | 18-2 | 19-1 | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| a, % Composition of Sandstone | | | | | | | | | | |
| i, Quartz | 68 | 73 | 76 | 62 | 63 | 68 | 67 | 67 | 70 | 68 |
| ii, Rock Fragments | | | | | | | | | | |
| Shale Fragments | 5 | 5 | 1 | 5 | 7 | 1 | 3 | 4 | 2 | 4 |
| Chert | 5 | 8 | 5 | 12 | 7 | 3 | 1 | 7 | 5 | 6 |
| Total rock fragments | 10 | 13 | 6 | 17 | 14 | 4 | 4 | 11 | 7 | 10 |
| Carbonates | 6 | - | 1 | 3 | 7 | 2 | 3 | 2 | - | 3 |
| iii, Feldspars | | | | | | | | | | |
| Potassium Feldspar | 2 | 7 | Tr.[2] | 4 | 3 | 5 | 6 | 4 | 9 | 4 |
| Plagioclase | Tr.[2] | Tr.[2] | 1 | 1 | Tr.[2] | Tr.[2] | Tr.[2] | Tr.[2] | Tr.[2] | Tr.[2] |
| Total Feldspars | 2 | 7 | 1 | 5 | 3 | 5 | 6 | 4 | 9 | 5 |

1 - Based upon a point count of more than 200 grains of essential components.

2 - Tr. means less than 1%

TABLE VIII Continued

| Sample No. | 11-6 | 12-4 | 13-3 | 14-2 | 15-2 | 16-1 | 17-2 | 18-2 | 19-1 | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| iv, Miscellaneous Carbonaceous Fragments | 2 | 2 | 13 | 5 | 5 | 4 | 11 | 3 | 2 | 5 |
| Collophane | 4 | 1 | 1 | - | - | 5 | 2 | 1 | 2 | 2 |
| Pyrite | 7 | 3 | 2 | 8 | 9 | 11 | 7 | 12 | 10 | 8 |
| b, Essential Components | | | | | | | | | | |
| i, Quartz | 79 | 78 | 90 | 71 | 72 | 86 | 83 | 80 | 82 | 80 |
| ii, Rock Fragments | 19 | 14 | 8 | 23 | 24 | 8 | 9 | 15 | 8 | 14 |
| iii, Feldspars | 2 | 8 | 2 | 6 | 4 | 6 | 8 | 5 | 10 | 6 |

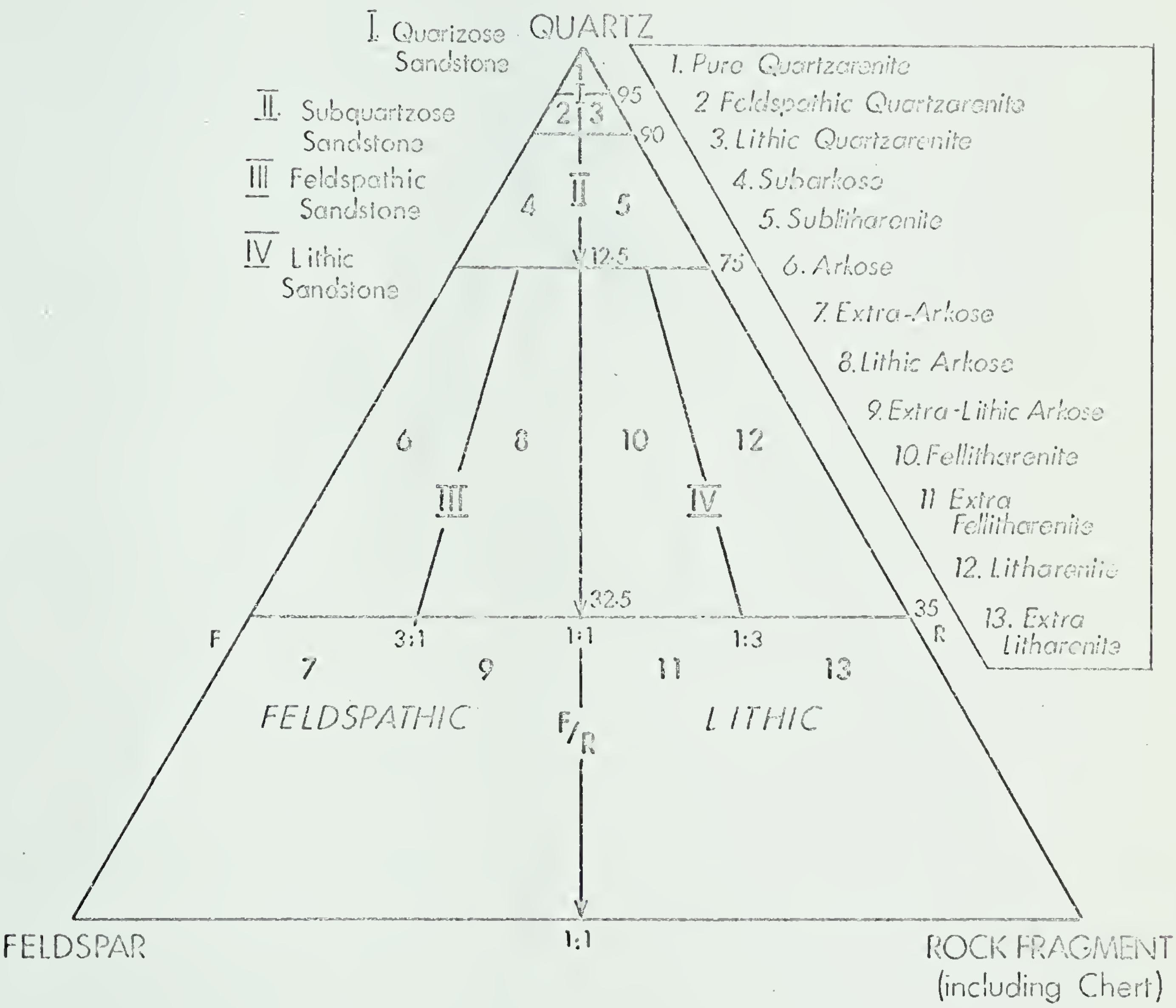



FIGURE 13 – Sandstone Classification & Nomenclature
(after Pei-Yuan Chen, 1968)

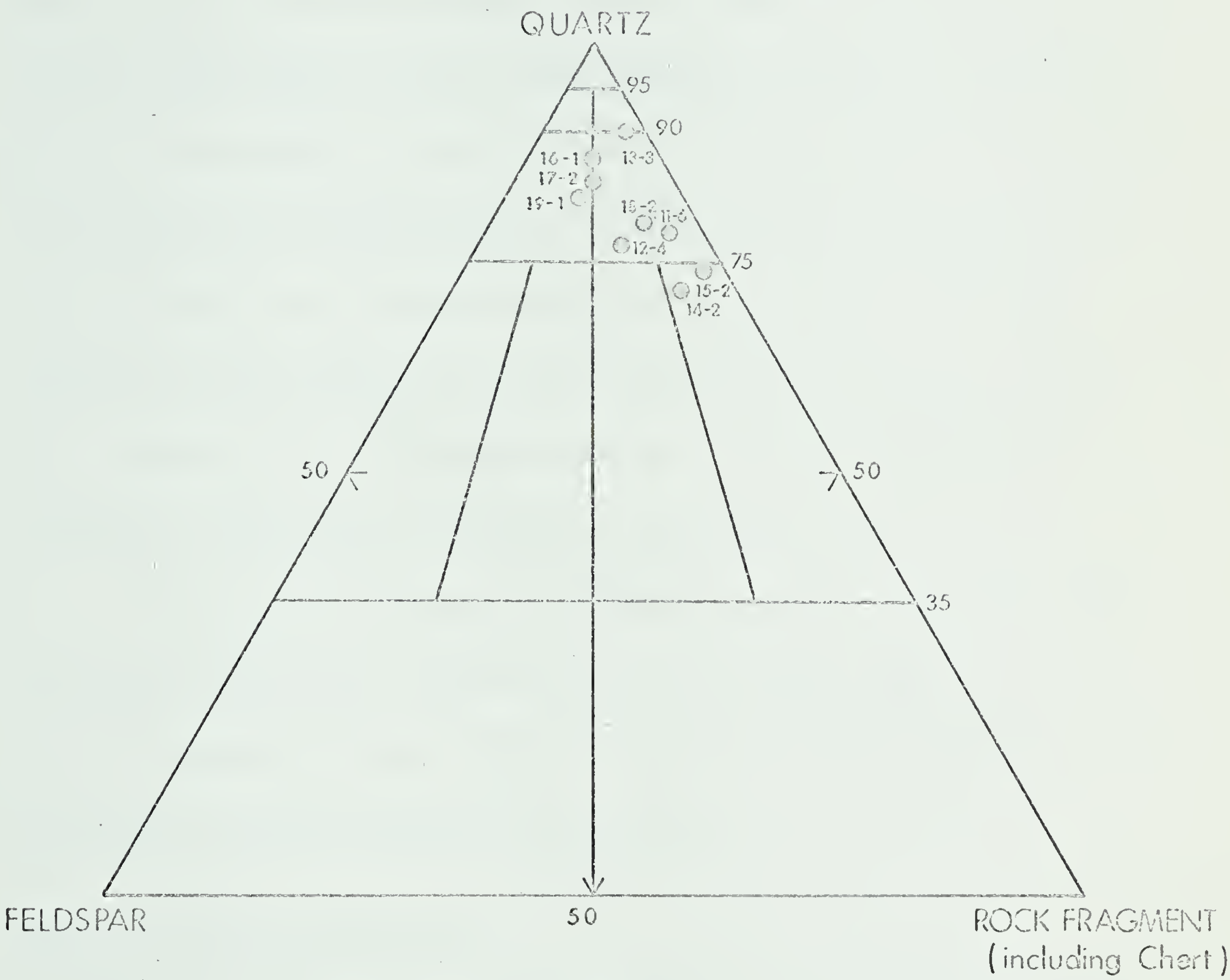



FIGURE 14 — Compositional Classification of Medicine Hat Sandstone

*(after Pei -Yuan Chen, 1968)*

with rock fragments. The nomenclature is based on the quartz content and the ratio of feldspars to the lithic fragments (Figure 13).

The respective percentages of the essential components of Medicine Hat Sandstone, namely quartz, feldspar and rock fragments, when plotted on the ternary diagram of Chen's classification (Figure 14), show that seven of the nine samples fall into the class of subquartzose sandstone (four of which belong to the sublitharenite subclass, one to the subarkose subclass, and two samples lie on the boundary between these two subclasses), and the remaining two samples can be termed litharenite. Their areal distribution cannot be delineated on the basis of this limited study.

In terms of terminology based on maturity of the rocks, this sandstone which has a detrital matrix percentage higher than 15% in the majority of cases, falls into the category of immature to very immature muddy sandstones (Chen, 1968).

Heavy Accessory Minerals

Detrital heavy minerals may be less than 0.1% of the total composition of the Medicine Hat Sandstone. The finer fractions (-120 +230 U.S. Standard mesh) are richer in some of the heavy minerals such as zircon, whereas the coarser fractions are comparatively poor in all such heavy minerals.

The small vertical thickness of the Medicine Hat Sandstone does not warrant a detailed examination of its heavy minerals

related to different vertical horizons. The purpose of this study was to determine the various types of heavy minerals present and to help in establishing the provenance of the sandstone. To accomplish this objective five samples were selected from different parts of the Medicine Hat Gas pool. The locations of these samples are given in Appendix A.

An appropriate quantity of chips from the core samples was crushed using an iron mortar. The crushed material was further ground on a glass slab with a light wooden roller to ensure the maximum possible disintegration. The granular product so obtained was dry sieved using numbers 60, 120, and 230 (U. S. Standard sieves). The -60 +120 fraction was processed with tetrabromoethane (S. G. 2.94 @ 20$^{o}$C). Those minerals having specific gravity higher than 2.94 settled to the bottom of the separating funnel and were collected on filter paper. This heavy fraction was washed with acetone and dried. A hand magnet was used to separate the magnetic minerals from this heavy fraction of the sandstone and the remainder was mounted on glass slides using Aroclor ($n = 1.66$) as the mounting medium. A visual estimation only of the heavy mineral content of the slides was made, revealing no obvious variation in heavy mineral types from one part of the field to another. The non-opaque heavy minerals are present in the following order of abundance in the Medicine Hat Sandstone:

1. Biotite
2. Apatite
3. Zircon
4. Hornblende
5. Tourmaline
6. Garnet
7. Collophane

Traces of epidote, spinel, rutile, and chlorite were also encountered.

Pyrite constitutes the main opaque mineral component and also makes up the bulk of the heavy minerals present.

A brief description of each of the minerals mentioned above is given below:

1. Pyrite: The pyrite is subangular to subrounded, elongated with some irregular shaped grains.

A characteristic brassy metallic luster under reflected light distinguishes the mineral from the other opaque minerals. Igneous, sedimentary or metamorphic origin's may be assigned to this mineral or it may be authigenic in nature. It signifies reducing environments, especially under marine conditions for the deposits in which it is present, and therefore is generally associated with black or dark grey clays or muds which are products of reducing environments (Milner 1962).

2. Biotite: Three varieties based on difference in colour (light reddish brown to dark reddish brown, green and colourless) are present, but the brown variety is dominant. The colourless variety may be formed by leaching of iron from darker grains. Biotite is generally subangular to subrounded. Inclusions generally occur in the brownish variety and consist of minute black, spherical to square shaped bodies. Biotite may have an igneous or metamorphic source; reddish brown biotite is considered to be derived from regionally metamorphosed rocks (Lerbekmo 1963).

According to Milner (1962) fresh biotite is present in quantity in sealed deposits, especially lenticular sandstone associated with clays or shales.

3. Apatite: Colourless apatite is common in the Medicine Hat Sandstone. It occurs as subhederal, prismatic, elongated, occasionally egg-shaped crystals. It is subangular to subrounded. The shape of the grain suggests that apatite may be a second cycle mineral.

Apatite may be derived from igneous rocks, especially granite and syenite. It is relatively soluble in acid solutions but survives in argillaceous impervious or sealed sediments rather than in arenaceous, porous rocks. Apatite is usually present in siltstones, shales or red marls, which are common products of continental, lacustrine, fluviatile, rarely marine environments (Milner 1962).

4. Tourmaline: Light green to dark green and brown varieties of tourmaline occur as subhederal, angular to subangular, prismatic, fresh-appearing grains. Inclusion of irregular-shaped, minute, opaque crystals are often present.

5. Hornblende: Hornblende is light to dark green in colour. It has a subhedral, angular to subangular shape, and a fresh appearance. It may have an igneous or metamorphic source, and fresh hornblende may indicate deposition in a "sealed" rock unit. The green variety is comparatively more stable than the brown variety and is favoured by marine environments (Milner 1962).

6. Garnet: Light pink coloured and colourless varieties of garnet are abundant in one of the five mounts prepared. In the remaining samples only traces of garnet are present. It is generally present in subhederal to anhederal form and is subangular with zircon inclusions. Generally, it has a fresh appearance.

Garnet is generally derived from the contact metamorphic zones, though it may also come from acid igneous rocks.

7. Zircon: Zircon is colourless to light purple coloured, subangular to rounded, euhederal to subhederal and with prismatic shape. It forms the bulk of the heavy minerals in finer fractions and is relatively less abundant in the coarser fractions. Inclusions are rare to absent. In some cases it has a 'dirty' appearance. If subrounded to rounded its grains are probably indicative of several

cycles of erosion, transportation and deposition.

Zircon may be derived from acid and intermediate igneous rocks.

8. Collophane: Light brown and colourless varieties of collophane are common in the heavy minerals of the Medicine Hat Sandstone. It is subangular, subhederal to anhederal, elongated and sometimes irregularly shaped. It has a very weak birefringence and in some cases it is isotropic. Wavy extinction is characteristic of the collophane grains which show birefringence. Relief of the grains is moderate.

Organic remains in the sandstone and enclosing shale such as fish scales, may have provided an ample source for its formation.

## Clay Mineralogy

General Statement: Under the binocular microscope and in thin section the Medicine Hat Sandstone exhibits a high proportion of shaly material. Thin section studies reveal that clay minerals are present in the form of matrix in the sandstone. As the detailed study and identification of clay minerals in sandstones by conventional microscopic methods is neither satisfactory nor reliable, it was deemed necessary to examine the clays present by applying x-ray diffraction techniques. The x-ray diffraction technique employed for the determination of the clay minerals was purely of a qualitative

nature and did not provide any information concerning the quantity of clay minerals present. One sample from each of four wells having a representative geographic distribution, in the area west of the Fourth Meridian was selected for the determination of clay minerals. The locations of these samples are shown in Appendix A.

<u>Sample Preparation</u>: Samples from the four wells were separately disintegrated by agitating them in water. The coarser fraction was allowed to settle over a 5 to 10 minute interval, and the finer particles remaining in suspension were separated from the coarser ones by decanting them into another beaker. The decanted fraction was thoroughly mixed with distilled water, using an electric rotary blender with 1 to 2 grams of calgon, added to prevent the flocculation of clay particles. The mixture was left in a 1000 ml. cylinder for one hour in order to enable the particles coarser than 4 microns to settle. At the end of this interval 50 ml. of the mixture was withdrawn by pipette from a depth of 5 cms. This mixture was considered to contain only particles of up to 4 microns diameter. This mixture was allowed to settle over a frosted glass slide in a beaker for 24 hours thus depositing all the particles coarser than 1/2 micron on the slide. The supernatant liquid was then removed from the beaker using a pipette and the slide was allowed to dry in air at room temperature for 24 - 48 hours. The sample preparation tends to orient clay minerals

parallel to the slide so that planar (001) reflections are intensified in the subsequent x-ray analysis.

Analytical Procedure: The x-ray diffraction unit used in this study is a Phillips-Norelco type 12045B/3 x-ray diffractometer with a geiger counter, using nickel-filtered, copper radiation produced by a Phillips-Norelco type 12045B/3 generator. The unit was operated at 35 KV and 15 MA, with a scale factor, multiplier and time constant of 4, 1, and 1 respectively. The diffractograms were obtained by running the chart paper at a speed of 1/2 inch per minute, scanning a range of $4^{\circ}$ to $30^{\circ}$ $2\theta$ at a rate of one degree $2\theta$ per minute. This scan interval was found to include all the principal peaks of all the clay minerals present in the samples.

Each of the samples was x-rayed in its untreated form, with each producing strong peaks at 13.7 Å, 10 Å, 7.1 Å, 4.99 Å, 3.57 Å and 3.31 Å. The intensity of the peaks was slightly less in those samples from the northern part of the field.

The samples were then sprayed with ethylene glycol and left for 12 to 16 hours. This process expands the montmorillonite lattice and helps to differentiate this mineral from other non-expanding clay minerals. The glycolated slides were then x-rayed, utilizing the same machine settings as were used for the untreated samples, producing diffractograms which showed no shifting of the peaks. This was taken to indicate that expanding clays were not

present in the samples.

The third step in the procedure involved heating the slides to 550°C. ± 10°C. for one hour. This procedure provided a check on the presence of kaolinite which was suspected of being in the samples. The heated samples when x-rayed, clearly showed the collapse of kaolinite peaks at 7.1 Å but a low peak at 3.57 Å, though losing its intensity, persistedafter heat treatment.

X-ray Mineral Identification: A comparative examination of the diffractograms showed that the pattern is generally unchanged from one sample to another, indicating that there is little or no variation in the type of clay from one part of the field to the other.

Clay minerals were identified by comparing peak positions with the location of peaks for different standard clay minerals (Molloy and Kerr, 1961). Chlorite, kaolinite, illite and quartz were identified in each of the samples. Figure 15 shows the character of the diffractometer traces for several samples.

Table IX briefly summarizes x-ray diffraction data for the most common clay minerals and the effect of glycolation and heating on different minerals in oriented samples.

The prominent peaks in the untreated samples are at 13.7 Å, 10 Å, 7.1 Å, 4.99 Å, 3.57 Å, and 3.31 Å which correspond to various values of basal reflections of chlorite, kaolinite and illite. Glycolation does not seem to have any effect on any of these peaks


FIGURE 15 - Diffractograms from the clay mineral samples of the Medicine Hat Sandstone Member

TABLE IX X-ray Diffraction Patterns of Oriented Clay Samples in Untreated, Glycolated and Heated Conditions

(Modified after Maiklem 1962)

| | Clay Mineral | Untreated | Glycolation | Heating $550^{\circ}C \pm 10C$ for one hour |
|---|---|---|---|---|
| 1. | Kaolinite | $d_{001}=7Å$ | No effect | Mineral destroyed |
| 2. | Chlorite | $d_{001}=14Å$ | Rarely affected | Decreases 001 intensifies peaks. Lower order peaks showing loss of intensity. |
| 3. | Illite | $d_{001}=10Å$ | No effect | No effect |
| 4. | Montmorillonite | $d_{001}=12.5Å$ or $15Å$ | Expands to $d_{001}$ $17Å$ | Collapses to $10Å$ |
| 5. | Vermiculite | $d_{001}=14Å$ | Expands to $15.5Å$ | $10Å$ |
| 6. | Mixed Layer Clay | $d_{001}=24Å$ $29Å$ | May change depending on components | May change depending on components |

suggesting the absence of expanding clay minerals (e. g. montmorillonite and vermiculite). The heated samples when x-rayed show no 7.1Å ($d_{001}$) peaks for kaolinite but a very weak peak in two of the four heated samples at 3.57Å (kaolinite $d_{002}$) persists and suggests that the kaolinite structure did not entirely collapse, which may indicate that the samples were not heated to the proper temperature of 550° (± 10°C).

The 13.7 Å peak in the diffractogram is interpreted as chlorite $d_{001}$ exclusively. It shows variation in its intensity from sample to sample but is persistent. This peak is not affected by glycolation but heating seems to destroy it, as it is not found on the diffractograms for the heated samples. The only peaks persisting throughout the treatment are those of illite ($d_{001}$=10Å, $d_{002}$=4.99 Å, and $d_{003}$=3.31 Å) the latter probably being combined with quartz ($d_{00?}$) in the samples under study.

## CHAPTER FIVE - SUMMARY AND CONCLUSIONS

I. The stratigraphic analysis of the section from the top of the Milk River Formation to the base of the Medicine Hat Sandstone Member carried out in this study has shown that:

i. The present day structure on top of the Medicine Hat Sandstone Member consists of an asymmetric anticline (Medicine Hat structure) confined to the southwestern part of the area under study. Other structures present include small scale "lows" and "highs" on a broad homocline dipping to the northeast. The similarity between the structural pattern on top of the Medicine Hat Sandstone and the top of the Colorado Group indicates that most of the structures are post-Colorado in time. Isopach maps of the interval between these markers however, indicate a thinning over the field area, suggesting that structural and/or topographic relief may have been present over the field during deposition of these sediments.

ii. Isopach and isolith maps of the Medicine Hat Sandstone Member show that it is an elongated body with a general west to east trend having an average thickness of 37 feet, of which, on the average, sand

constitutes up to 20 feet. These maps reveal a clear pinching out of the sandstone body in all directions though the limits of the body are difficult to delineate.

iii. There does not appear to be any relationship between the structural configuration of the top of the Medicine Hat Sandstone and the isopach trends, although the higher isolith values coincide with the higher elevations in the southwestern part of the area, suggesting a convex-upward shape of the sand concentrations.

iv. Stratigraphic and structural cross-sections show that the sand body was deposited on an approximately horizontal plane parallel to the top of the Colorado Group. Thickening of the Milk River Formation and a generally corresponding thinning of the Colorado Shale in the north has no effect on the thickness of the Medicine Hat Sandstone.

v. The present day structural setting of the area shows that the sandstone body occurs on the northeastern flank of the Sweetgrass Arch and that it gradually thins towards the northeast.

vi. Lithologically the Medicine Hat Sandstone is generally

grey coloured, friable to compact, fine grained, thinly bedded, and very rich in regular to irregular shaly streaks of variable thickness. Carbonaceous and organic material is generally present. Contacts of the sand with the enclosing shale are gradational. Sedimentary structures present include horizontal to slightly oblique bedding, and burrowings are common, suggesting low velocity, quiet water conditions of deposition.

II Petrographically the Medicine Hat Sandstone is composed of quartz, chert, shale and detrital carbonate rock fragments and potassium feldspar as its essential components. Pyrite, biotite, apatite, zircon, hornblende, tourmaline and collophane are present as accessories. The rock is classified as a subquartzose sandstone under Chen's (1968) scheme of classification. Matrix is the primary binding material but in some sections calcite cement is present. Replacement of shaly streaks by calcite veins is observed.

Texturally, the sandstone is very fine to fine grained, with elongated, subangular to subrounded grains, poorly packed, suggestive of a comparatively short history of transportation and rapid deposition.

Sorting is only moderate, but calcite cemented parts are well sorted indicating higher primary porosity in those parts of the

sandstone body.

No significant lateral or vertical variation in the composition and texture of the sandstone was observed, suggesting that the factors responsible for the deposition of this sandstone body over a large area were similar in nature and magnitude.

The pyrite component of the heavy minerals is most probably authigenic in origin whereas the apatite, biotite and hornblende may have been derived from volcanic rocks in the source area. A possibility of the derivation of all the heavy accessory minerals of the Medicine Hat Sandstone from volcanic ash in the enclosing Colorado Shale cannot be ruled out.

III Comparing the Medicine Hat Sandstone with other sandstone bodies of Upper Cretaceous age such as the Cardium and Milk River Formations as reported by other authors shows that lithologically these stratigraphically separate sandstone bodies are similar in composition, texture and their high shale content. The areal extent of the Medicine Hat Sandstone is, however, limited as compared to the Cardium or Milk River Formations. The Medicine Hat Sandstone differs, in that it is a shallow marine deposit without known lateral non-marine equivalents and is entirely enclosed in the Colorado Shale. The source of the Medicine Hat Sandstone cannot be inferred from its stratigraphic position and lateral relationships. On the other hand, Cardium and Milk River Sandstones show trans-

gressions and regressions of the sea and clearly point to a western source for the coarse clastics. It seems possible that waves and currents may have reworked the Colorado Shale winnowing out the silt to very fine grained sand fraction from muddy sediments producing a moderately sorted, dirty arenaceous material in this general area which may have been a shoal in a shallow sea.

IV. Statistical comparison of the data obtained directly from electric and radiation logs for 22 wells and from the systematic sampling of the maps constructed with the values from these two sources, by using a linear regression model indicates that:

i. Isopach values derived from electric and radiation logs are not comparable, having a low correlation coefficient (R). The data cannot be statistically combined to construct maps and cross-sections.

ii. A relatively better correlation coefficient (R) for the isopach values of the Medicine Hat Sandstone Member from the two types of logs is obtained by comparing data from that part of the field with maximum well density. However, a decrease in the value of correlation coefficient (R) was observed when the isopachs of the Colorado Shale interval between the top of the Colorado Group and the top of the Medicine Hat Sandstone were compared in

the same area.

iii. The structural elevation values for the top of the Medicine Hat Sandstone Member and the top of the Colorado Group, obtained from the two types of logs are highly correlative. The combination of electric log and radiation log data of this type is justified statistically for this general area.

iv. Sections i and iii above are inconsistent when the interval between the top of the Colorado Group and the top of the Medicine Hat Sandstone Member is considered. It is thought that the low correlation coefficient (R) for this isopach interval may be due to an insufficient number of samples when data from the 22 common wells are compared and to contouring errors when data from the maps are compared.

v. The comparison of the sand isolith values calculated from the electric logs by adding the sandy zones showing a 5 millivolt and 10 millivolt or higher spontaneous potential deflections on the electric log curve, shows the existence of a high degree of correlation between the two sets of values, suggesting that the selection of either of these two

arbitrary limits for the definition of net sand thickness of the Medicine Hat Sandstone Member has the same geological significance. A higher value of net sand thickness is obtained if a 5 millivolt spontaneous potential deflection is selected as the arbitrary limit for the definition of sandstone.

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# APPENDIX A

## Location of Samples

LEGEND

T - Thin Sections Unusable

T* - Examined Thin Section

T** - Compositional minerals grain counted

M - Heavy mineral sample

C - X-ray diffraction sample

1. Medicine Hat #7-20

Lsd. 7, Sec. 20, Twp. 11, Rge. 6 W4M.

Elevation: 2417' K. B.

Depth below K. B. (feet)

1065.0 T**C

1070.0 T

1075.0 T

2. Canadian Export Gas Medicine Hat

Lsd. 10, Sec. 27, Twp. 12, Rge. 2 W4M.

Elevation: 2785' K. B.

Depth below K. B. (feet)

1547.8 T*M

1552.8 T

1557.8 T

1562.8 T

1568.5 T

3. Calvan Medicine Hat

Lsd. 6, Sec. 29, Twp. 12, Rge. 3 W4M.

Elevation: 2572' K. B.

Depth below K. B. (feet)

1432.0 T

1437.0 T

1441.5 T

4. Canadian Delhi Pashly 1

Lsd. 11, Sec. 35, Twp. 12, Rge. 4 W4M.

Elevation: 2513' K. B.

Depth Below K. B. (feet)

1324.0 T*

1329.0 T

1334.0 T

1339.0 T

1344.0 T*

1349.0 T**

5. City of Medicine Hat 6-25

Lsd. 6, Sec. 25, Twp. 12, Rge. 5 W4M.

Elevation: 2417' K. B.

Depth below K. B. (feet)

1185.0 T

1190.0 T

1195.0 T**

1204.0 T

6. Saxet Medicine Hat

Lsd. 6, Sec. 17, Twp. 13, Rge. 1 W4M.

Elevation: 2393' K. B.

Depth below K. B. (feet)

1410.0 T*

1415.0 T

7. Britalta Crescent Medicine Hat 6-29

Lsd. 6, Sec. 29, Twp. 13, Rge. 2 W4M.

Elevation: 2391' K. B.

Depth below K. B. (feet)

1368.0 T*

1373.0 T

1378.0 T*

1384.2 T

8. Britalta Crescent Medicine Hat 10-17

Lsd. 10, Sec. 17, Twp. 13, Rge. 3 W4M.

Elevation: 2546' K. B.

Depth below K. B. (feet)

1405.0 T*

1405.5 T*

1413.0 T*

1418.0 T*

1423.0 T*

1428.0 T*

1430.0 T*

9. Dom Glass Medicine Hat

Lsd. 6, Sec. 34, Twp. 13, Rge. 6 W4M.

Elevation: 2431' K. B.

Depth below K. B. (feet)

1225.0 T

1230.0 T

1235.0 T*

1245.0 T*CM

1250.0 T

10. Medicine Hat 6-13

Lsd. 6, Sec. 13, Twp. 14, Rge. 2 W4M.

Elevation: 2438' K. B.

Depth below K. B. (feet)

1403.0 T

1428.0 T*

1437.0 T**

1456.0 T

1457.0 T

1462.0 T

11. Medicine Hat 10-18

Lsd. 10, Sec. 18, Twp. 14, Rge. 3 W4M.

Elevation: 2474' K. B.

Depth below K. B. (feet)

1386.0 T

1388.0 T

1391.0 T

1396.0 T

12. Guyer Medicine Hat

Lsd. 6, Sec. 29, Twp. 15, Rge. 1 W4M.

Elevation: 2726' K. B.

Depth below K. B. (feet)

1790.0 T

1795.0 T

1810.0 C

13. Canadian Delhi Medicine Hat

Lsd. 6, Sec. 5, Twp. 15, Rge. 2 W4M.

Elevation: 2604' K. B.

Depth below K. B. (feet)

1602.0 T*

1607.0 T**

1617.0 T

14. Canadian Delhi Medicine Hat

Lsd. 10, Sec. 28, Twp. 15, Rge. 3 W4M.

Elevation: 2600' K. B.

Depth below K. B. (feet)

1591.0 T

1594.0 T

1609.0 T

15. Mic Mac Medicine Hat

Lsd. 10, Sec. 25, Twp. 15, Rge. 4 W4M.

Elevation: 2471' K. B.

Depth below K. B. (feet)

1438.0 T

1443.0 T*

1448.0 T*

16. Mic Mac Medicine Hat

Lsd. 11, Sec. 23, Twp. 15, Rge. 5 W4M.

Elevation: 2372' K. B.

Depth below K. B. (feet)

1209.0 T

17. NCO Schuler Medicine Hat

Lsd. 11, Sec. 21, Twp. 16, Rge. 1 W4M.

Elevation: 2723' K. B.

<u>Depth below K. B. (feet)</u>

1884.0 T**

1889.0 T

1898.0 T

18. Canex Schuler Medicine Hat

Lsd. 11, Sec. 27, Twp. 16, Rge. 2 W4M.

Elevation: 2716' K. B.

<u>Depth below K. B. (feet)</u>

1817.5 T

1827.5 T

19. Canadian Delhi Medicine Hat

Lsd. 6, Sec. 1, Twp. 16, Rge. 3 W4M.

Elevation: 2699' K. B.

<u>Depth below K. B. (feet)</u>

1737.5 T*

20. Mic Mac Medicine Hat

Lsd. 7, Sec. 23, Twp. 16, Rge. 4 W4M.

Elevation: 2553' K. B.

<u>Depth below K. B. (feet)</u>

1524.2 T

21. Canex Hilda Medicine Hat

Lsd. 11, Sec. 36, Twp. 17, Rge. 2 W4M.

Elevation: 2510' K. B.

<u>Depth below K. B. (feet)</u>

1665.0 T*M

1670.0 T**

22. Britala Hilda Medicine Hat

Lsd. 7, Sec. 6, Twp. 18, Rge. 2 W4M.

Elevation: 2526' K. B.

<u>Depth below K. B. (feet)</u>

1669.0 T**

1674.0 T*C

23. Cancrude Hilda

Lsd. 10, Sec. 26, Twp. 19, Rge. 1 W4M.

Elevation: 2451' K. B.

<u>Depth below K. B. (feet)</u>

1664.0 T**M

24. R. O. C. Hilda

Lsd. 6, Sec. 32, Twp. 19, Rge. 2 W4M.

Elevation: 2354' K. B.

<u>Depth below K. B. (feet)</u>

1578.0 T*

25. R. O. C. Hilda

Lsd. 7, Sec. 27, Twp. 20, Rge. 4 W4M.

Elevation: 2751' K. B.

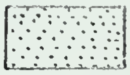
Depth below K. B. (feet)

1430.0 T

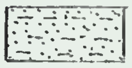
# APPENDIX B

## Selected Electric & Radiation Logs of Wells

LEGEND

 Milk River Formation

 Upper Colorado Shale Formation

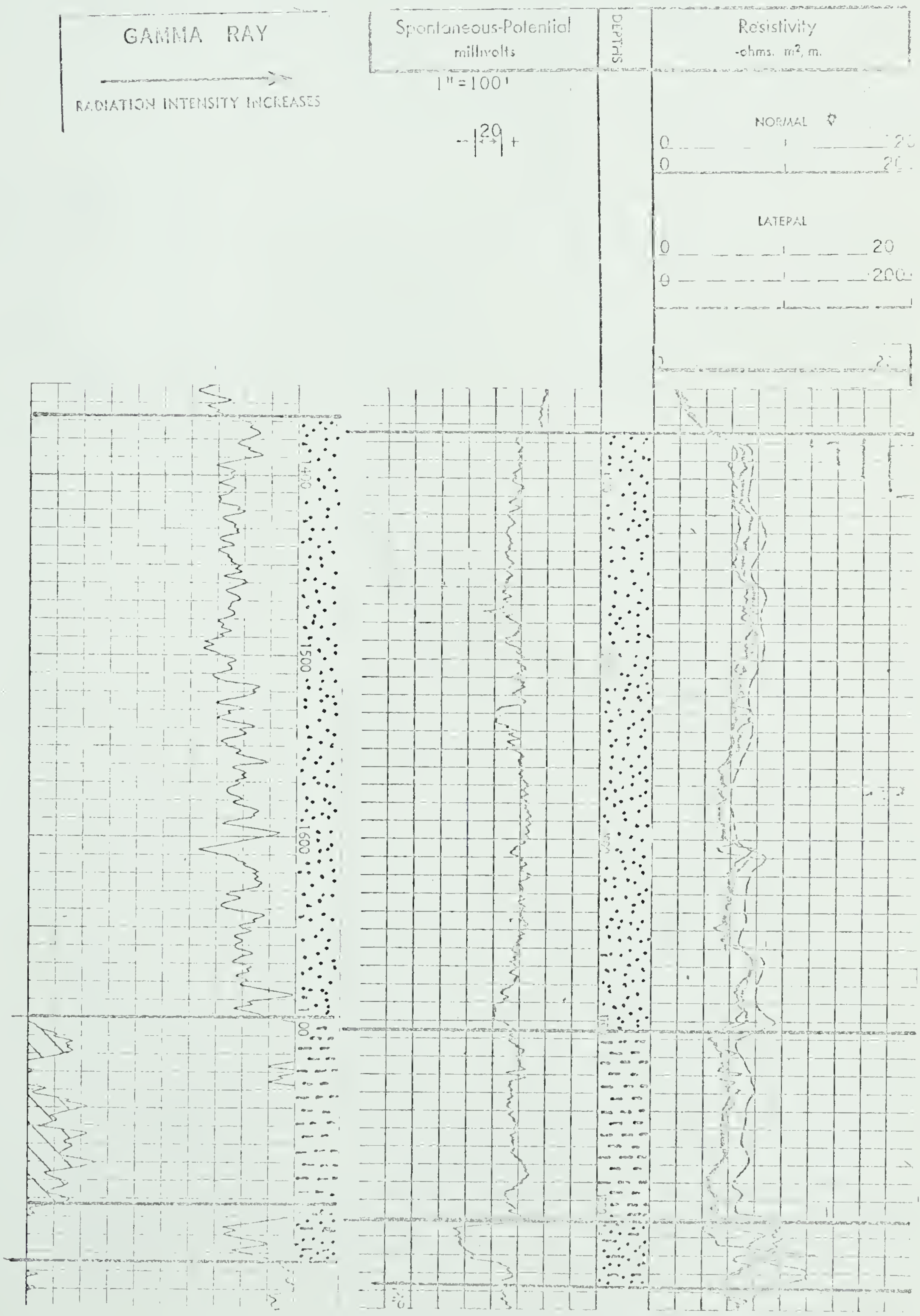
 Medicine Hat Sandstone Member

Albercan Boxelder Creek #1

Lsd. 4, Sec. 12, Twp. 11, Rge. 30, W3M.

Elev. 2727' (K. B.)

Mud Resistivity 2.0 ohms. $m^2$/m. @ 72°F.



Mic Mac et al Hilda

Lsd. 6, Sec. 12, Twp. 19, Rge. 2, W4M.

Elev. 2445' (K. B.)

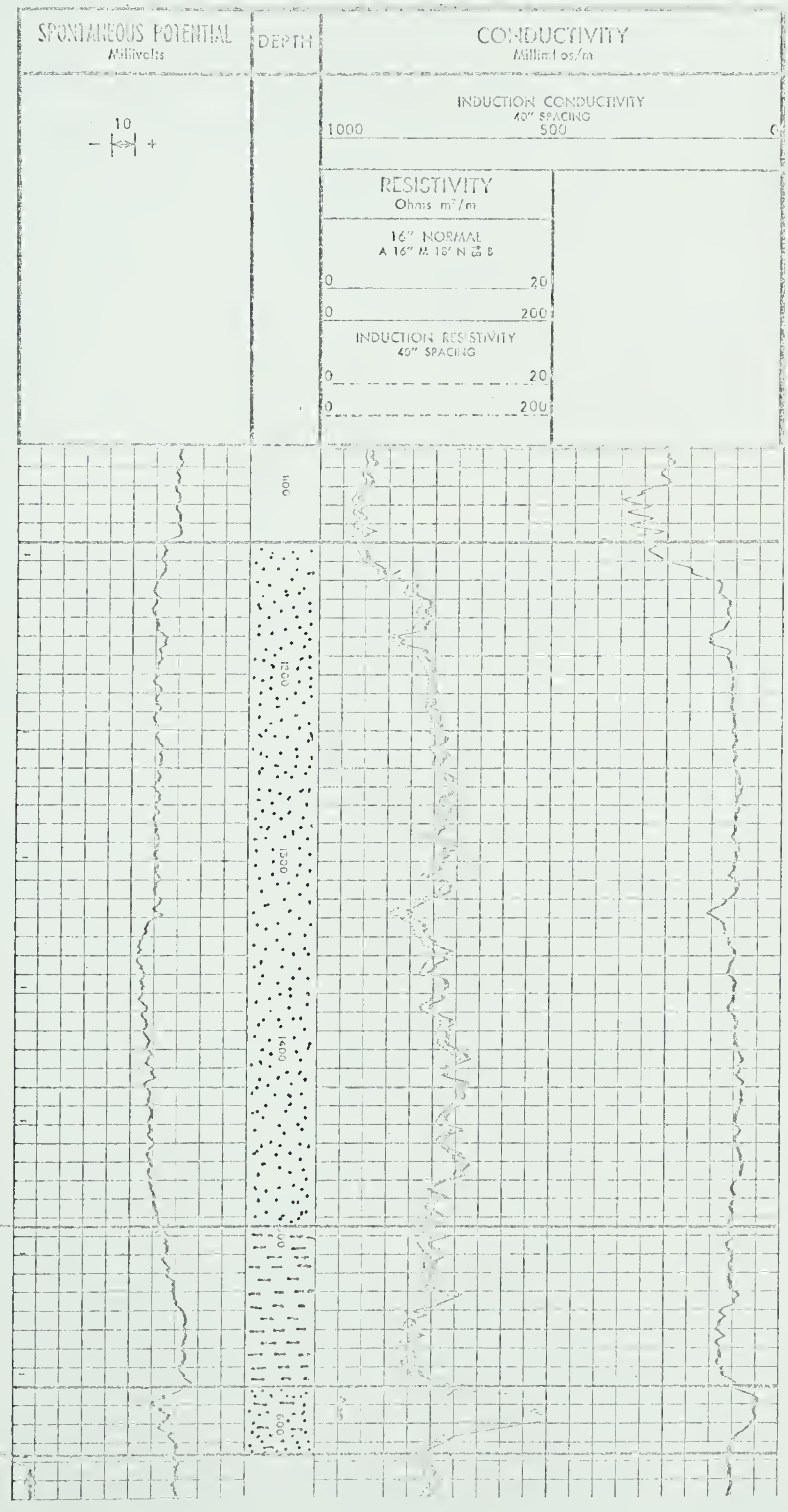
Mud Resistivity 5.0 ohms. $m^2/m$. @ $60^oF$.

Many Islands Pipeline Medicine Hat

Lsd. 11, Sec. 34, Twp. 14, Rge. 2, W4M.

Elev. 2587' (K. B.)

Mud Resistivity 1.4 ohms. $m^2/m.$ @ $72^{\circ}F.$

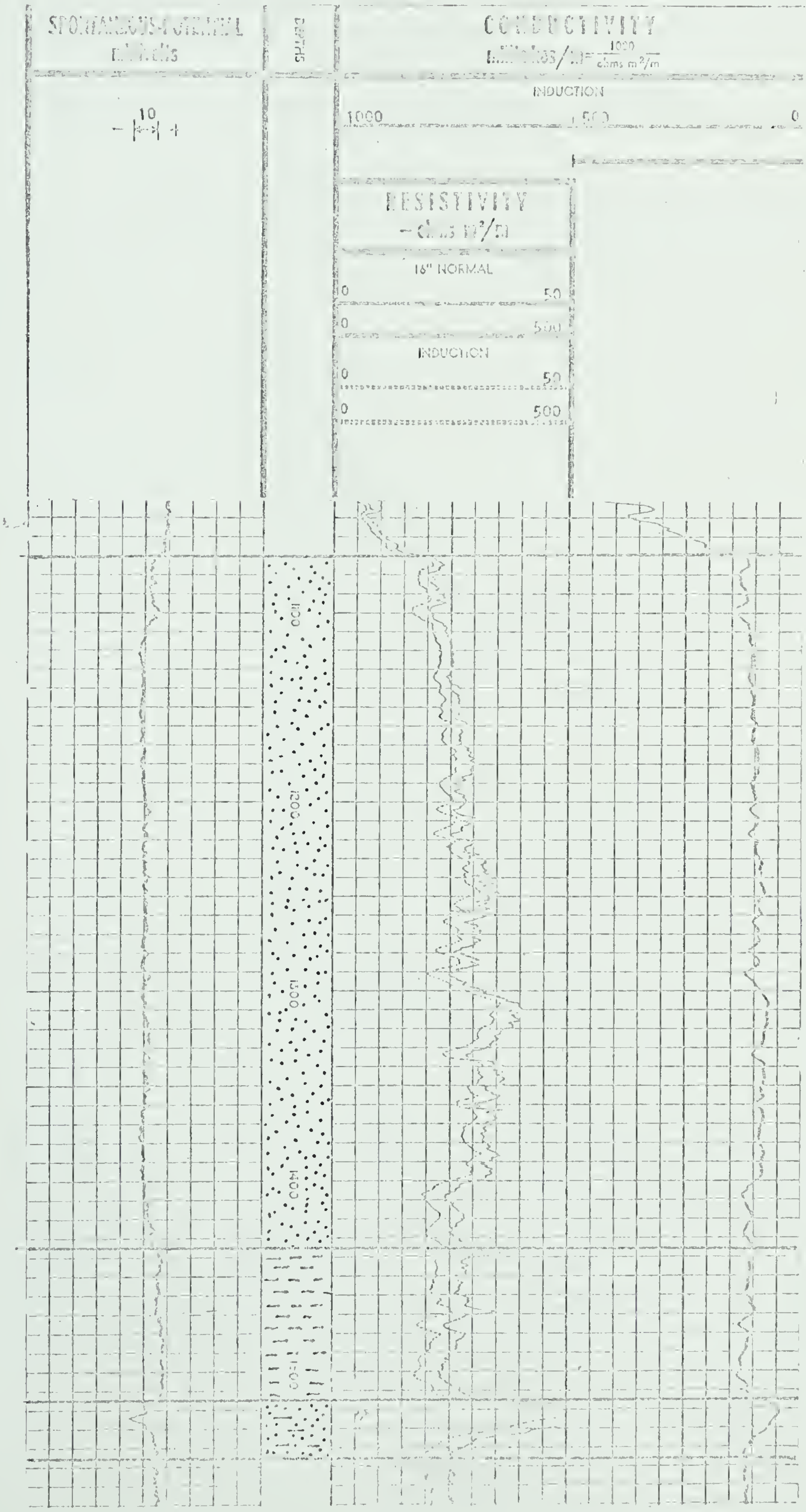


Canex Medicine Hat

Lsd. 11, Sec. 28, Twp. 17, Rge. 3, W4M.

Elev. 2433' (K. B.)

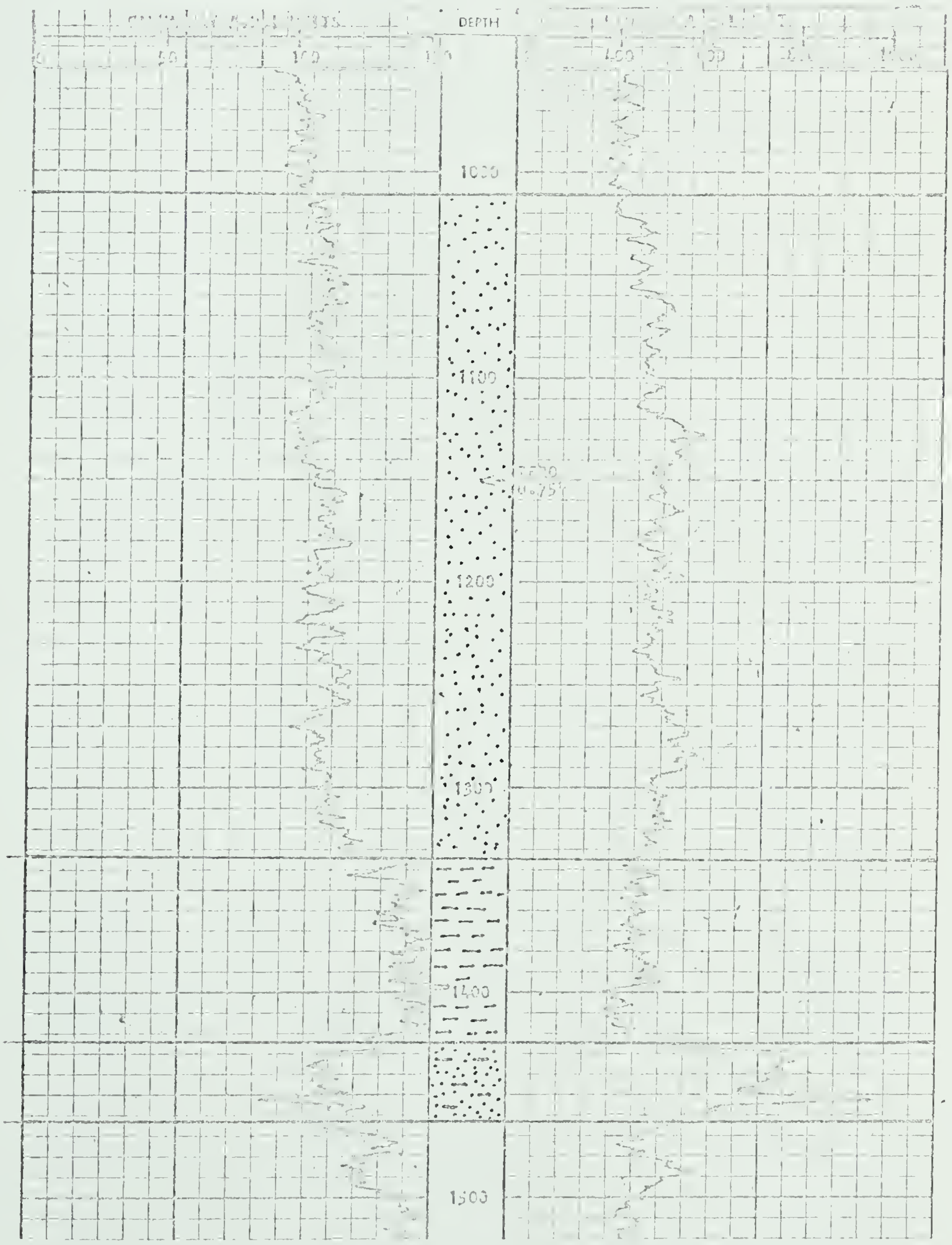
Mud Resistivity 3.07 ohms. $m^2$/m. @ 58°F.



Many Islands Pipeline Medicine Hat

Lsd. 6, Sec. 22, Twp. 13, Rge. 3, W4M.

Elev. 2550' (K. B.)

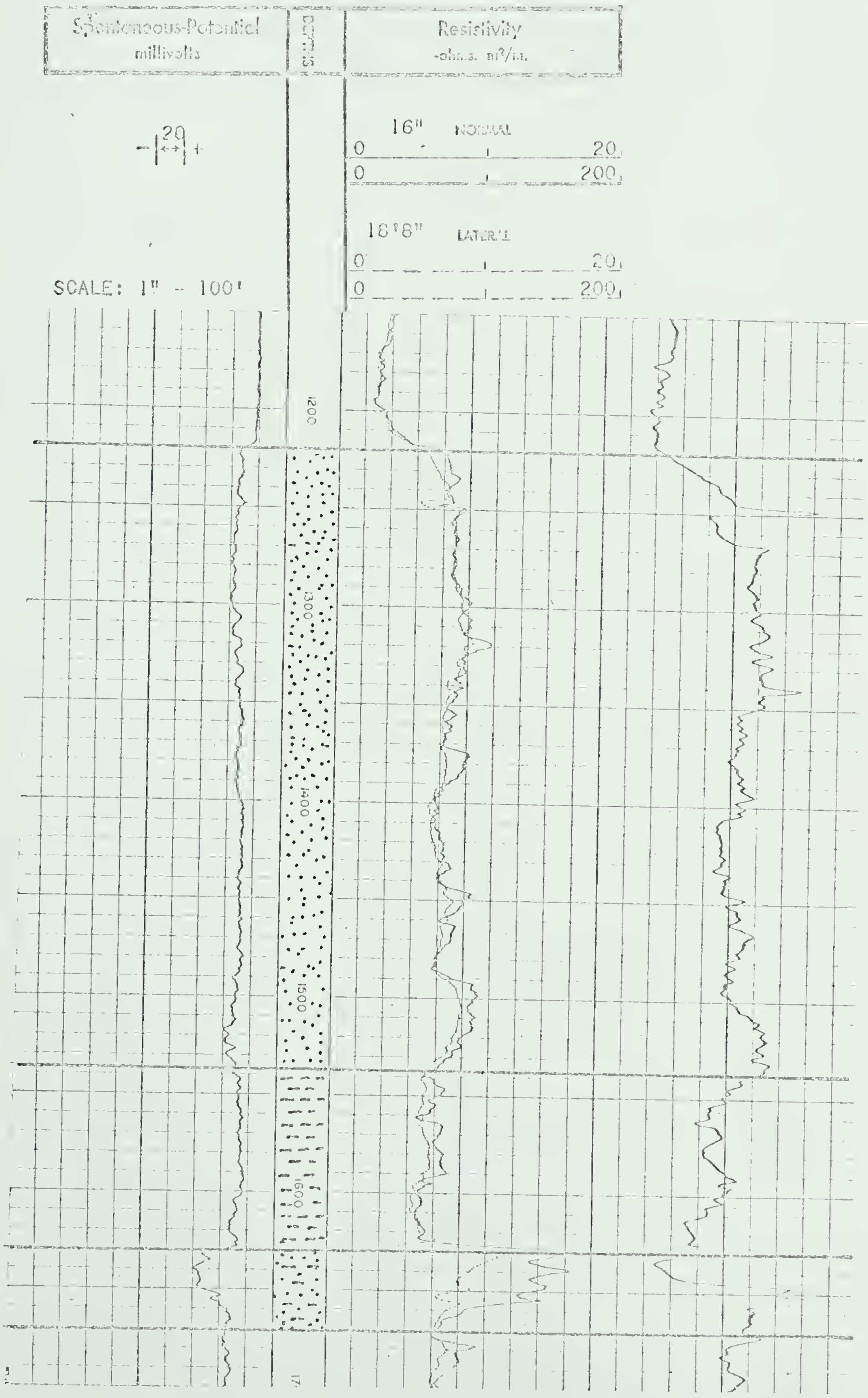


Miller Pyrcz #7-28

Lsd. 7, Sec. 28, Twp. 12, Rge. 2, W4M.

Elev. 2687' (K. B.)

Mud Resistivity 5.2 ohms. $m^2/m.$ @ $54^oF.$



Rothwell et al. Hatton

Lsd. 10, Sec. 36, Twp. 14, Rge. 27, W3M.

Elev. 2423' (K. B.)

Mud Resistivity 3.78 ohms. $m^2/m$. @ 78°F.

# APPENDIX C

## Selected Core Description

Canadian Export Gas Irvine

Lsd. 10, Sec. 20, Twp. 11, Rge. 2 W 4 Mer.

Elevation 2818' K. B.

Cored Interval 1719 to 1742 feet (23 feet)

Recovery 20 feet

| Depth | Thickness | |
|---|---|---|
| 1719' to 1733' 6" | 14' 6" | SANDSTONE, light to medium grey, "salt and pepper" fine to medium-grained, soft, friable to consolidated, fossiliferous, calcareous, thinly bedded, silty lenses present and becoming more common with depth. Sandstone grades to silty shale in its lower part. |
| 1733' 6" to 1734' 6" | 1' | SILTYSHALE, light to dark grey, fine grained, consolidated, calcareous, thinly bedded, generally unfossiliferous, showing the characteristics of a transitional zone from overlying sandstone to the underlying shale. |

| | | |
|---|---|---|
| 1734' 6" to 1739' | 4' 6" | SHALE, light to dark grey, consolidated, noncalcareous to calcareous, thinly bedded, unfossiliferous, thin streaks of silty and sandy material common, interlayed with the shale. |

Canadian Export Gas Medicine Hat

Lsd. 10, Sec. 27, Twp. 12, Rge. 2 W 4 Mer.

Elevation 2785' K. B.

Cored Interval 1540 to 1616 feet (76 feet)

Recovery 76 feet

| Depth | Thickness | |
|---|---|---|
| 1540' to 1547' 8" | 7' 8" | SHALE, dark grey, white speckled, compact and thinly bedded, fossiliferous, calcareous, grading to the underlying sandstone, the lower 3' showing an increase in the thickness of sandy layers with the sandstone being comparatively compact and fine grained. Bentonite layers of 1" thickness at 1540', |

| | | |
|---|---|---|
| | | 2" thickness at 1542' and 3" thickness at 1544' 6" present in the upper shaly part. |
| 1547' 8" to 1568' 6" | 20' 10" | SANDSTONE, light grey, fine to medium grained, friable to consolidated, fossiliferous, calcareous, thinly bedded, very thin streaks of siltstone and shale common in the lower part, a bentonite layer is present at 1551'. |
| 1568' 6" to 1580' | 11' 6" | SILTYSHALE, grey siltstone, light grey and shaly dark grey, interlayered, generally fine grained, compact, fossiliferous and calcareous. The upper part is rich in silty material but the shale content increases with depth and the interval grades to shale downward. |

| | | |
|---|---|---|
| 1580' to 1616' | 36' 0" | SHALE, dark grey, compact, fossiliferous, lower part richly calcareous and slightly silty, thinly bedded, 6" zone at 1596' is silty to sandy with alternate layers of siltstone/ sandstone and shale. |

City of Medicine Hat No. 6-25

Lsd. 6, Sec. 25, Twp. 12, Rge. 5 W 4 Mer.

Elevation 2417' K. B.

Cored Interval 1184 to 1214 feet (31 feet)

Recovery 30 feet

| Depth | Thickness | |
|---|---|---|
| 1184' to 1185' | 1' 0" | SILTYSHALE, light to dark grey, compact, fossiliferous, richly calcareous, thinly bedded, carbonaceous material present in silty layers, silty shale grades into underlying sandstone. |
| 1185' to 1193' 4" | 8' 4" | SANDSTONE, light grey, fine to medium grained, consolidated |

| | | |
|---|---|---|
| | | but not very compact, upper 2 to 3 feet friable, fossiliferous (Inoceramus fragments), calcareous, thinly bedded with carbonaceous material (coal fragments). The lower part of the interval is silty to shaly in layers. |
| 1193' 4" to 1194' | 0' 8" | SILTYSHALE, light to dark grey, compact, fossiliferous, calcareous, thinly bedded, grading to underlying sandstone. |
| 1194' to 1204' | 10' 0" | SANDSTONE, light to dark grey, fine to medium-grained, compact, fossiliferous, richly calcareous, thinly bedded and grading into the underlying silty shale. |
| 1204' to 1212' 6" | 8' 6" | SILTYSHALE, light to dark grey, the upper part comparatively rich in silt, the lower part dominantly shale, and the central |

| | | |
|---|---|---|
| | | part being a mixed interlayed zone. |
| 1212' 6'' to 1214' | 1' 6'' | SHALE, dark grey white speckled, compact, fossiliferous, calcareous, thinly bedded. |

Saxest Medicine Hat No. 6-17

Lsd. 6, Sec. 17, Twp. 13, Rge. 1 W 4 Mer.

Elevation 2393' K. B.

Cored Interval 1405 to 1461 feet (56 feet)

Recovery 56 feet

| Depth | Thickness | |
|---|---|---|
| 1405' to 1425' | 20' 0'' | SANDSTONE, light to medium grey, fine to medium-grained, friable to compact, slightly fossiliferous (Inoceramus fragments) calcareous, thinly bedded, bedding is generally horizontal. Intercalations of dark coloured white speckled and calcareous shale present in the sandstone. |

| | | |
|---|---|---|
| 1425' to 1430' | 5' 0" | SILTYSHALE, dark grey, white speckled, compact, fossiliferous with thin (up to 3 mm) layers of silt having carbonaceous material. Interval has a gradational contact zone with overlying and underlying lithologies. |
| 1430' to 1461' | 31' 0" | SHALE, dark grey, white speckled, compact, fossiliferous, thinly and well bedded, slightly siliceous. |

Britalta Crescent Medicine Hat No. 10-17

Lsd. 10, Sec. 17, Twp. 13, Rge. 3 W 4 Mer.

Elevation 2546' K. B.

Cored Interval 1390 to 1431 feet (42 feet)

Recovery 42 feet

| Depth | Thickness | |
|---|---|---|
| 1390' to 1403' | 14' 0" | SHALE, dark grey, white speckled, compact, calcareous, fossiliferous (Pelecypods and Inoceramus), thin silty-sandy layers become more abundant in lower |

| | | |
|---|---|---|
| | | 2' of the interval. Up to 1" thick, light grey, fossiliferous bentonitic zones, about 6" apart abundant in black shale in 1399 to 1401' zone. |
| 1403' to 1431' | 28' 0" | SANDSTONE, "salt and pepper", not very compact, soft, friable, containing abundant layers of shale 1 to 3 mm. in thickness. Upper one foot thin bedded, wavy, disrupted, bioturbated, calcareous, resistant sandstone, bedding even and horizontal, with tendency to blocky vertical fracture. Basal contact gradational by increasing frequency and thickness of shale beds with the lower 1' of interval dominantly shaly. Black and brown carbonaceous remains less than 2 mm thick common in lower part of core. Average porosity 29% (determined by Core Labora- |

tories Ltd.).

Dom Glass Medicine Hat No. 6-34

Lsd. 6, Sec. 34, Twp. 13, Rge. 6 W 4 Mer.

Elevation 2431' K. B.

Cored Interval 1210 to 1267 feet (57 feet)

Recovery 52.6 feet

| Depth | Thickness | |
|---|---|---|
| 1210' to 1220' | 10' 0" | SHALE, dark grey, white speckled, compact, consolidated, thinly bedded, fossiliferous, calcareousness increases with the abundance of fossil shell fragments of Inoceramus, 1" thick bentonite zone present at a depth of 1219' 3". Cut and fill structure is shown by the irregular shaped clots of silty/shaly material in the shale. |
| 1220' to 1225' | 5' 0" | SILTYSHALE, thin layers of silty/sandy material are intercalated with the dark shale. The frequency and percentage |

| | | |
|---|---|---|
| | | of coarser material increases with depth. Contact gradational between the overlying and underlying sandstone. The sandstone in the lower zone has thicker, irregular "salt and pepper" type of sandstone layers in white speckled shale. |
| 1225' to 1250' | 25' 0" | SANDSTONE, dark grey, generally compact with friable zones, thinly bedded, compact medium-grained dolomitic material 2" to 3" thick marks the lower contact of the sandstone with shale. Contact gradational with the underlying shale. A carbonaceous, fossiliferous and calcareous friable zone of 2 1/2" thickness is present in the sandstone 2 1/2' above the lower shale and sandstone contact. |
| 1250' to 1262' 6" | 12' 6" | SHALE, dark grey, white speckled, compact, thinly bedded, cal- |

| | | |
|---|---|---|
| | | careous, richly fossiliferous, cut and fill structures in shale, filling mostly by silty/sandy material. Two bentonite zones at the depths of 1257' 9" and 1261' with less than 1" individual thickness present in shale. |
| 1262' 6" to 1267' | 4' 6" | Core lost. |

Many Islands Pipeline Medicine Hat No. 6-13

Lsd. 6, Sec. 13, Twp. 14, Rge. 2, W 4 Mer.

Elevation 2438' K. B.

Cored Interval 1402 to 1477 feet (75 feet)

Recovery 72 feet

| Depth | Thickness | |
|---|---|---|
| 1402' to 1427' | 25' 0" | SHALE, dark grey, white speckled, compact, silty/sandy thin layers significant in the lower part and are distinguishable because of their lighter colour. |
| 1427' to 1432' | 5' 0" | SANDSTONE, "salt and pepper", very fine grained, micaceous, |

| | | |
|---|---|---|
| | | carbonaceous, calcareous. |
| 1432'to 1452' | 20' 0" | SHALE, dark grey, compact, fossiliferous, very thin light coloured silty zones, especially abundant in the lower part of the core. 1439'to 1442' Compact siliceous shale layers of upto 6" thickness and dark grey in colour present. A bentonite layer 1" thick at 1441' depth. |
| 1452' to 1466' | 14' 0" | SANDSTONE, "salt and pepper" fine grained, light to dark grey, not very compact, friable, thinly bedded, fossiliferous, calcareous, the upper part rich in silty material. It has gradational contact with underlying shale and lower part of the sandy section is dominantly shaly. A bentonite layer of 1" thickness at a depth of 1464'. |

| | | |
|---|---|---|
| 1467' to 1475' | 8' 0" | SHALE, dark grey, compact and calcareous. Average porosity 23% (determined by Core Laboratories Ltd.). |

Guyer Medicine Hat No. 6-29

Lsd. 6, Sec. 29, Twp. 15, Rge. 1 W 4 Mer.

Elevation 2726' K. B.

Cored Interval 1785 to 1835 feet (50 feet)

Recovery 50 feet

| Depth | Thickness | |
|---|---|---|
| 1785' to 1790' | 5' 0" | SHALE, dark grey, white speckled, compact, consolidated, thinly bedded, fossiliferous, slightly calcareous, cut and fill structures present. Silt/sand is generally the filling material in these structures. |
| 1790' to 1812' 6" | 22' 6" | SILTYSHALE, dark grey shale with light to medium grey coloured streaks of silt/sand. The silty/sandy layers are generally common in the central part of |

| | | |
|---|---|---|
| | | this section, the upper and lower parts are dominantly shaly. Shale is white speckled and varies from uncalcareous to calcareous. Calcareousness varies with the fossil fragment content. Shale is consolidated but its compactness varies from depth to depth. Cross-bedding at a depth of 1801' 4" observed. |
| 1812' 6" to 1835' | 22' 6" | SHALE, dark grey, consolidated upper contact zone of 1' thickness has silty material in it in the form of clots and thin layers. It is calcareous to noncalcareous, fossiliferous and thinly bedded. A 3" thick calcite rich, compact, light grey zone present at a depth of 1815' 9" interlayered with shale. A 2" thick bentonite layer of medium grey colour present at a depth of 1815'. |

Canadian Delhi Medicine Hat No. 6-1

Lsd. 6, Sec. 1, Twp. 16, Rge. 3 W 4 Mer.

Elevation 2699' K. B.

Cored Interval 1730 to 1750 feet (20 feet)

Recovery 20 feet

| Depth | Thickness | |
|---|---|---|
| 1730' to 1732' 6" | 2' 6" | SHALE, dark grey, compact, consolidated, calcareous and fossiliferous. Streaks of sandy and silty material present. The contact with the lower shaly-sandy zone is gradational. |
| 1732' 6" to 1742' 6" | 10' 0" | SHALY-SANDSTONE, light to medium grey coloured, fine to medium grained, thinly bedded, but shale interfingers and is white speckled. In the sandy zone cut and fill structure observed. The lower zone is rich in shale because of gradational lower contact, fossil fragments are present. It varies from calcareous to noncalcareous |

| | | |
|---|---|---|
| | | in nature. |
| 1742' 6" to 1750' | 7' 6" | SHALE, dark grey, white speckled, thinly bedded, consolidated, compact, fossiliferous with Inoceramus fragments common, calcareous, thin sandy/silty streaks present and their frequency and thickness increases in the upper part of this section of the core. |

Britalta Hilda Medicine Hat No. 7-6

Lsd. 7, Sec. 6, Twp. 18, Rge. 2 W 4 Mer.

Elevation 2526' K. B.

Cored Interval 1640 to 1690 feet (50 feet)

Recovery 40 feet

| Depth | Thickness | |
|---|---|---|
| 1640' to 1669' | 19' 0" | SHALE, dark grey, white speckled, compact, consolidated, calcareous, fossiliferous, carbonaceous fragments present. Four bentonite layers with 1/4", 2 1/2", 2", and 1/2" thicknesses are encountered at the depths of |

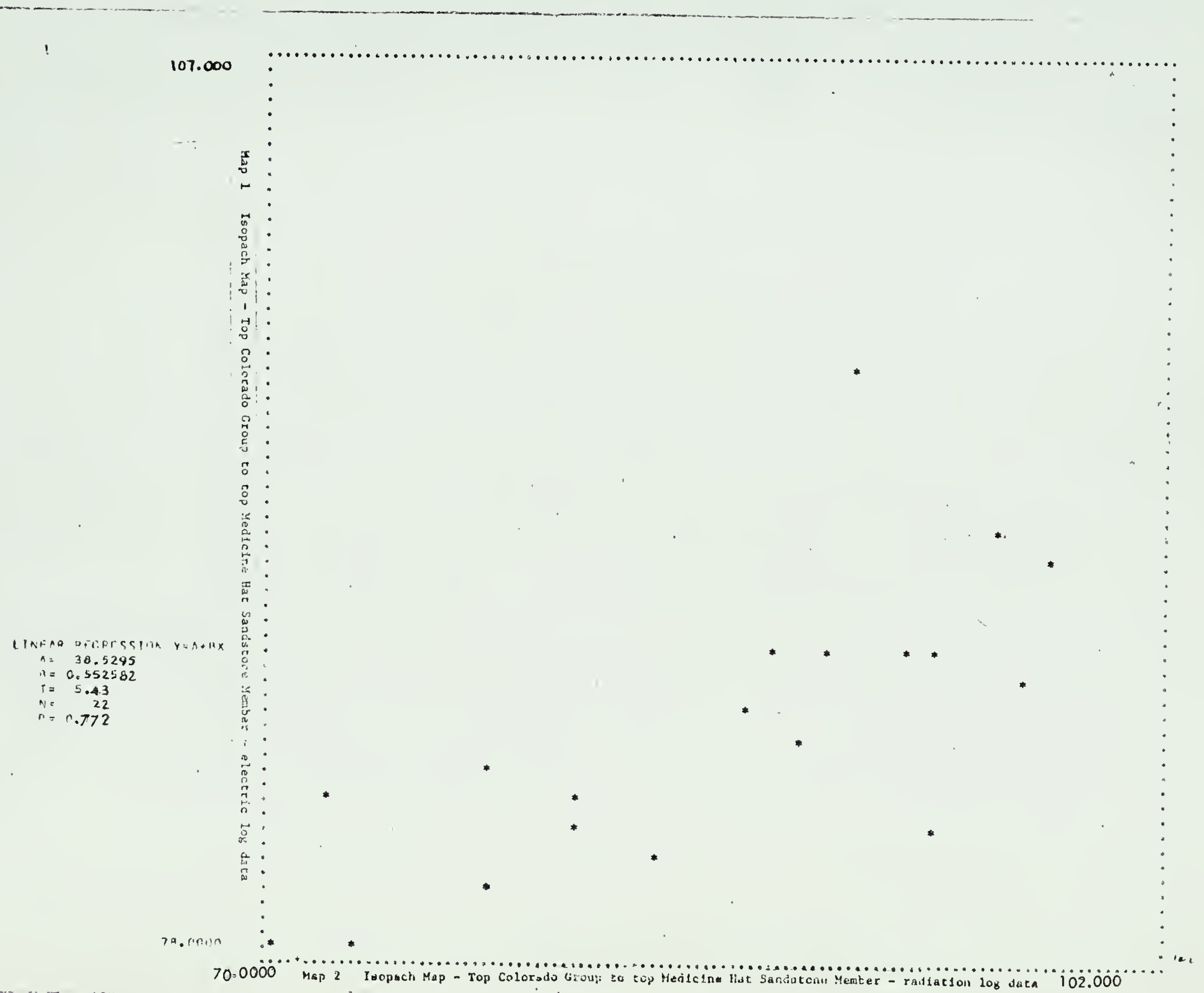
| | | |
|---|---|---|
| | | 1641' 4", 1646', 1661' and 1668' 3" respectively. The 2 1/2" thick bentonite layer is associated with micaceous material. The 2" thick bentonite layer at the depth of 1661' overlies a 1" thick pure fossiliferous limestone layer. The compactness in the lower part of this section decreases because of increase in silt content. The lower contact is gradational. |
| 1669' to 1685' 6" | 16' 6" | SHALY-SANDSTONE, medium grey, fine to medium-grained, compact, well consolidated, calcareous, fossiliferous, thinly bedded. Shale interlayers with silt/sand. The lower part of this section rich in shale and shows the gradational nature of the lower contact. Shale intercalations are white speckled and |

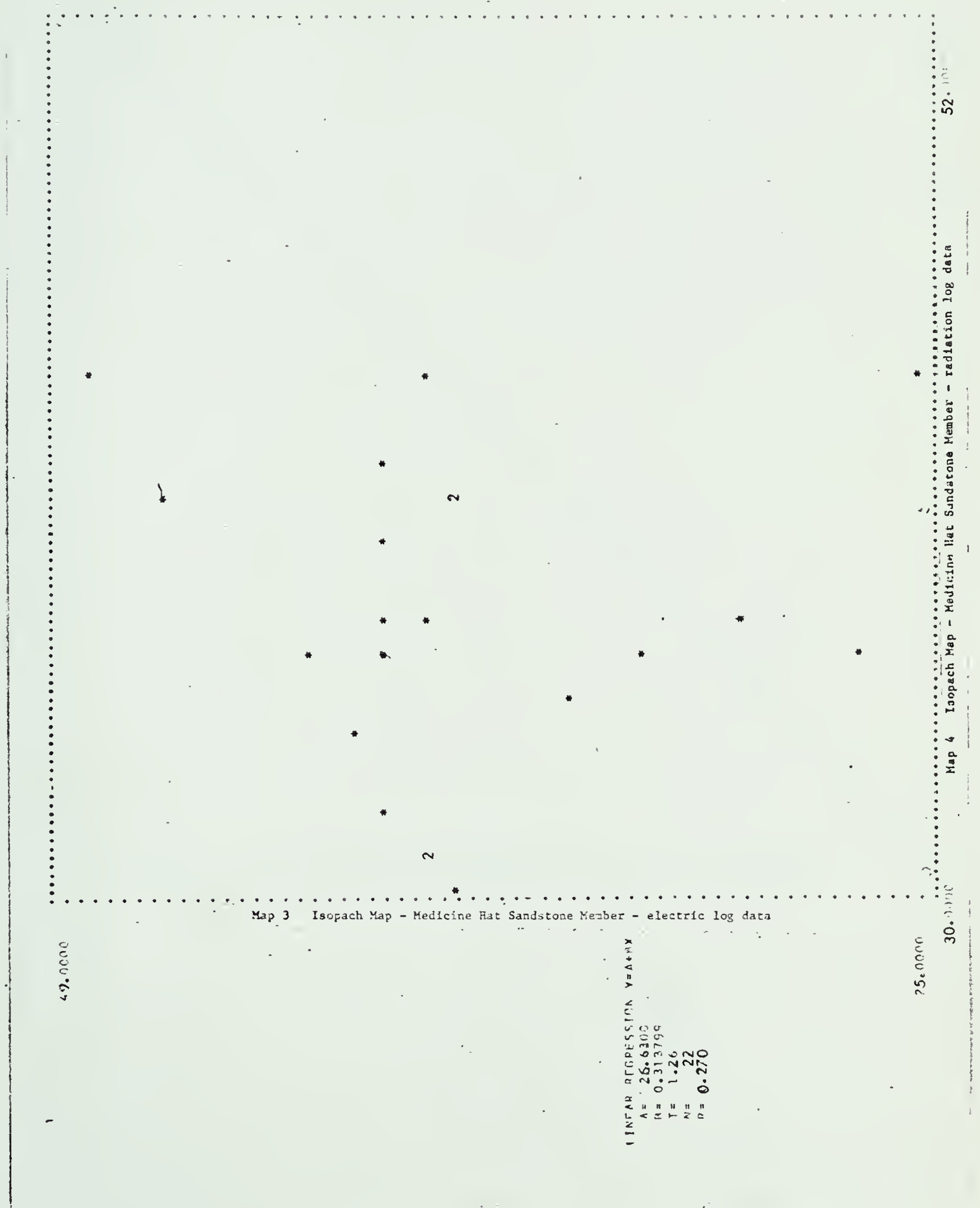
carbonaceous. Bedding is irregular and variable from one section to the other.

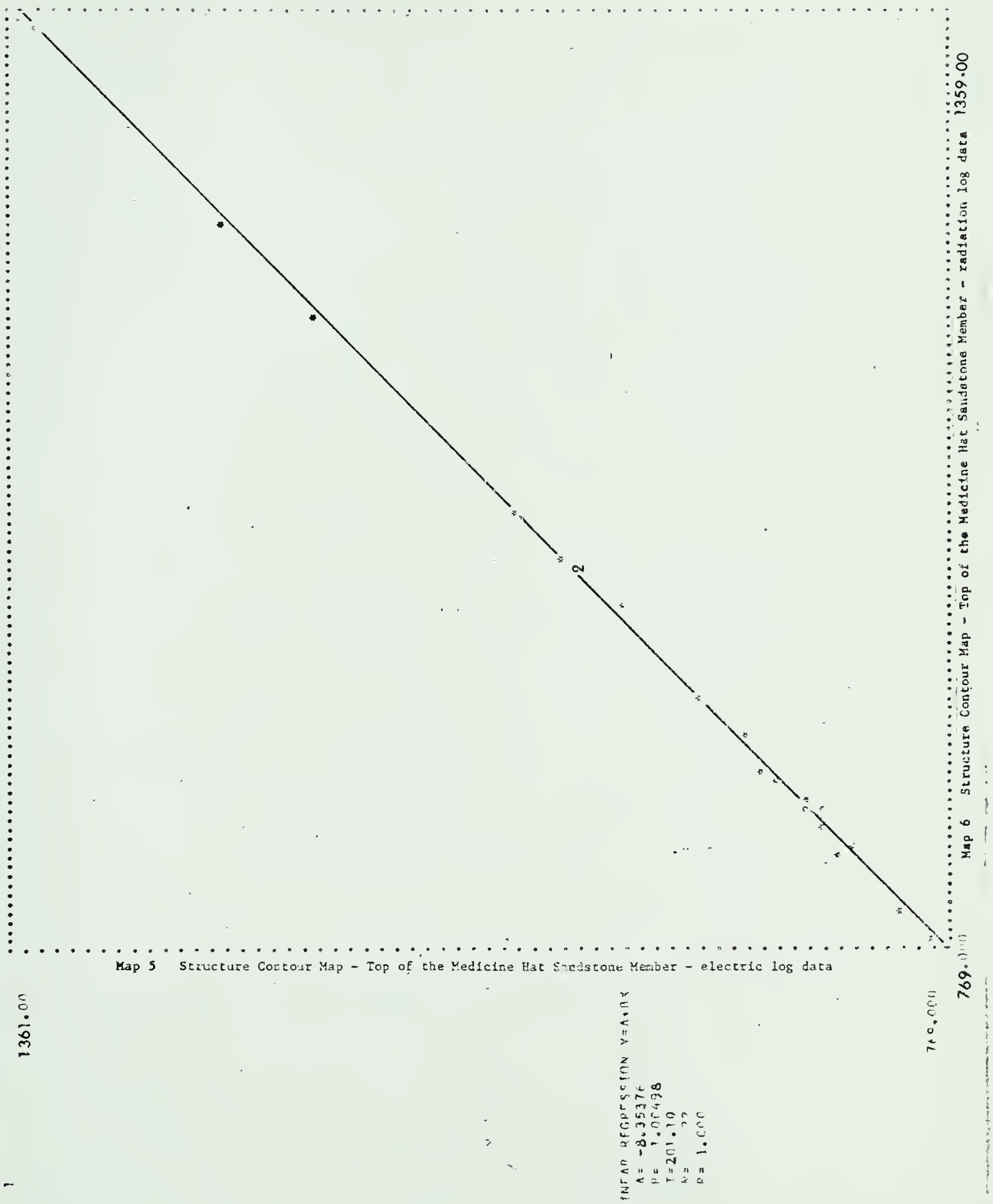
# APPENDIX D

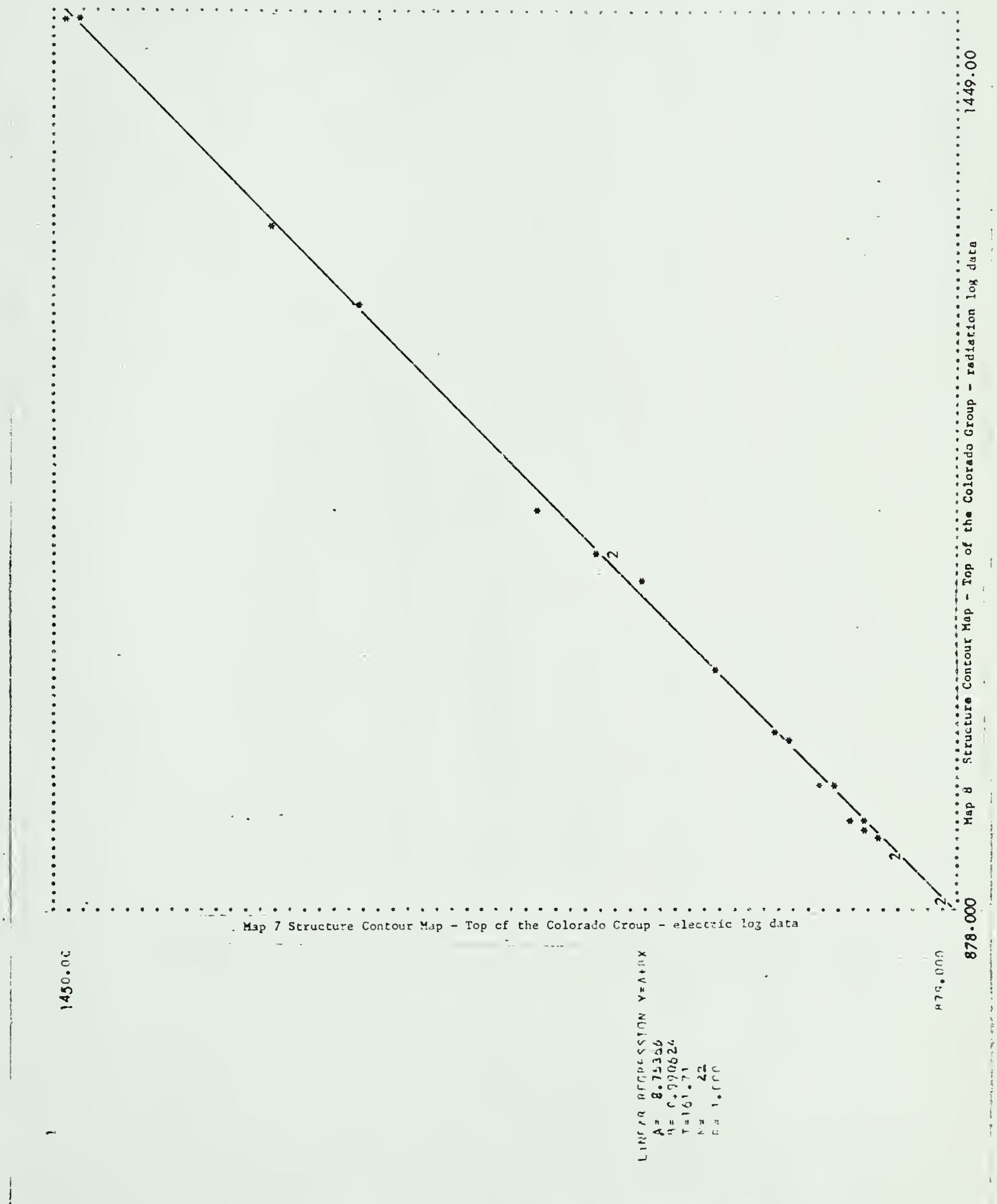
## Computer Outputs

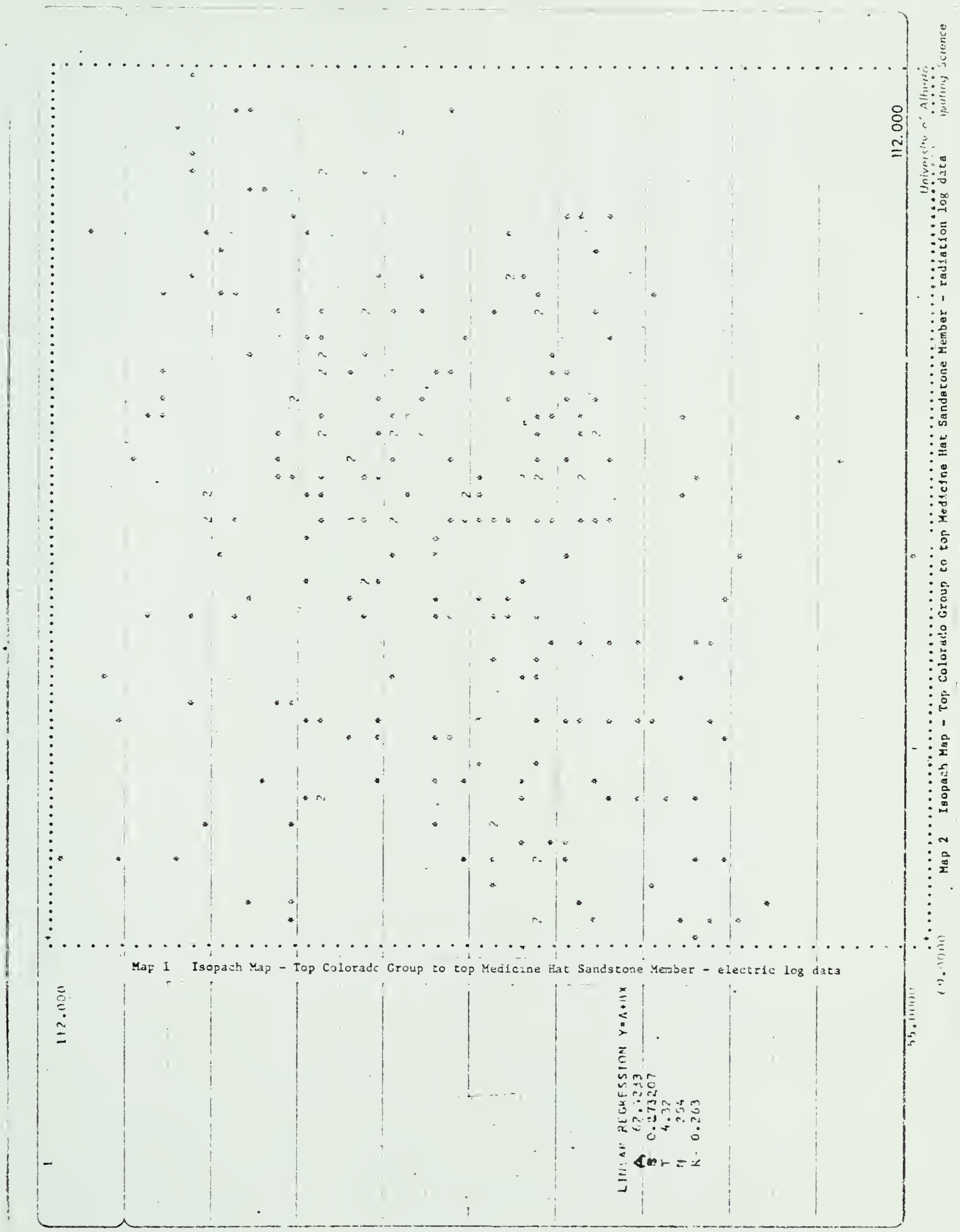
## Linear Regression Plots


107.000
78.0000
70.0000
102.000
Map 1 Isopach Map - Top Colorado Group to top Medicine Hat Sandstone Member - electric log data
Map 2 Isopach Map - Top Colorado Group to top Medicine Hat Sandstone Member - radiation log data
LINEAR REGRESSION Y=A+BX
A= 38.5295
B= 0.552582
T= 5.43
N= 22
R= 0.772


Map 3 Isopach Map - Medicine Hat Sandstone Member - electric log data
Map 4 Isopach Map - Medicine Hat Sandstone Member - radiation log data
49.0000
25.0000
30.
52.
LINEAR REGRESSION Y=A+BX
A= 26.6300
B= 0.313799
T= 1.26
N= 22
R= 0.270

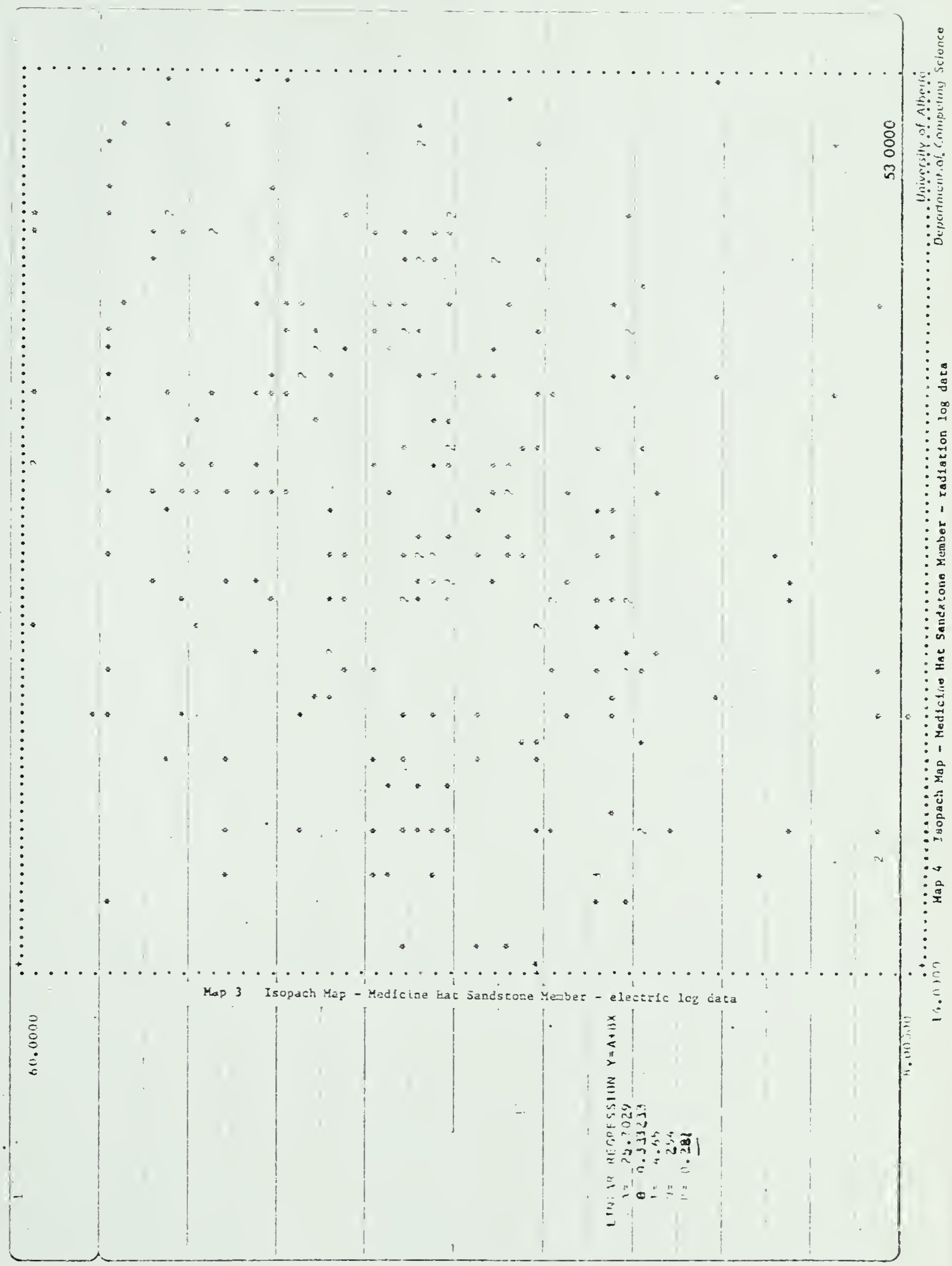

Map 5 Structure Contour Map - Top of the Medicine Hat Sandstone Member - electric log data
Map 6 Structure Contour Map - Top of the Medicine Hat Sandstone Member - radiation log data
1361.00
769.000
1359.00
LINEAR REGRESSION Y=A+BX
A= -8.35374
B= 1.00498
T=201.10
N= 22
R= 1.000


Map 8 Structure Contour Map - Top of the Colorado Group - radiation log data
1449.00
878.000
Map 7 Structure Contour Map - Top of the Colorado Group - electric log data
1450.00
LINEAR REGRESSION Y=A+BX
A= 8.75366
T=161.71
N= 22



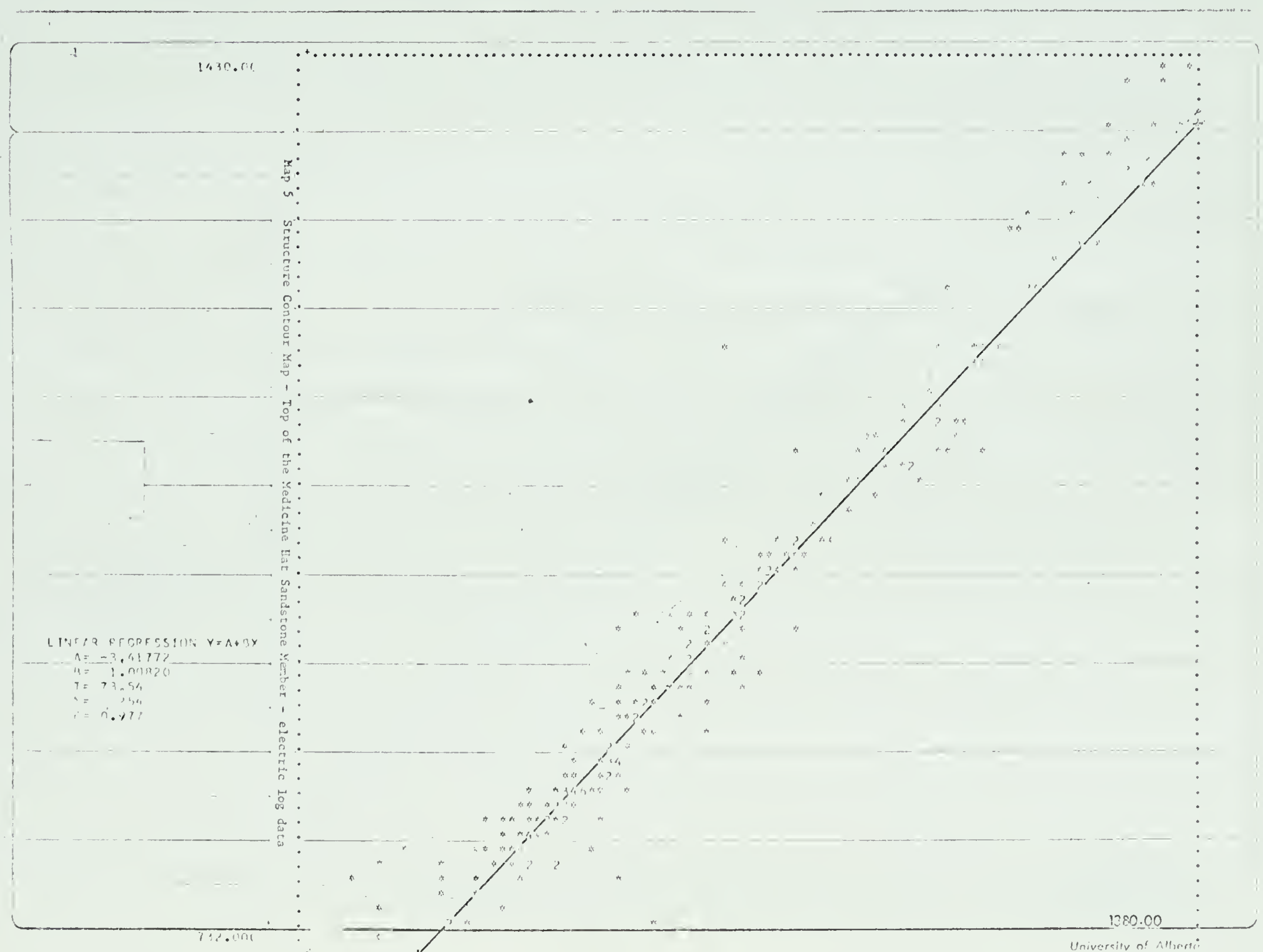

Map 1 Isopach Map - Top Colorado Group to top Medicine Hat Sandstone Member - electric log data

Map 2 Isopach Map - Top Colorado Group to top Medicine Hat Sandstone Member - radiation log data



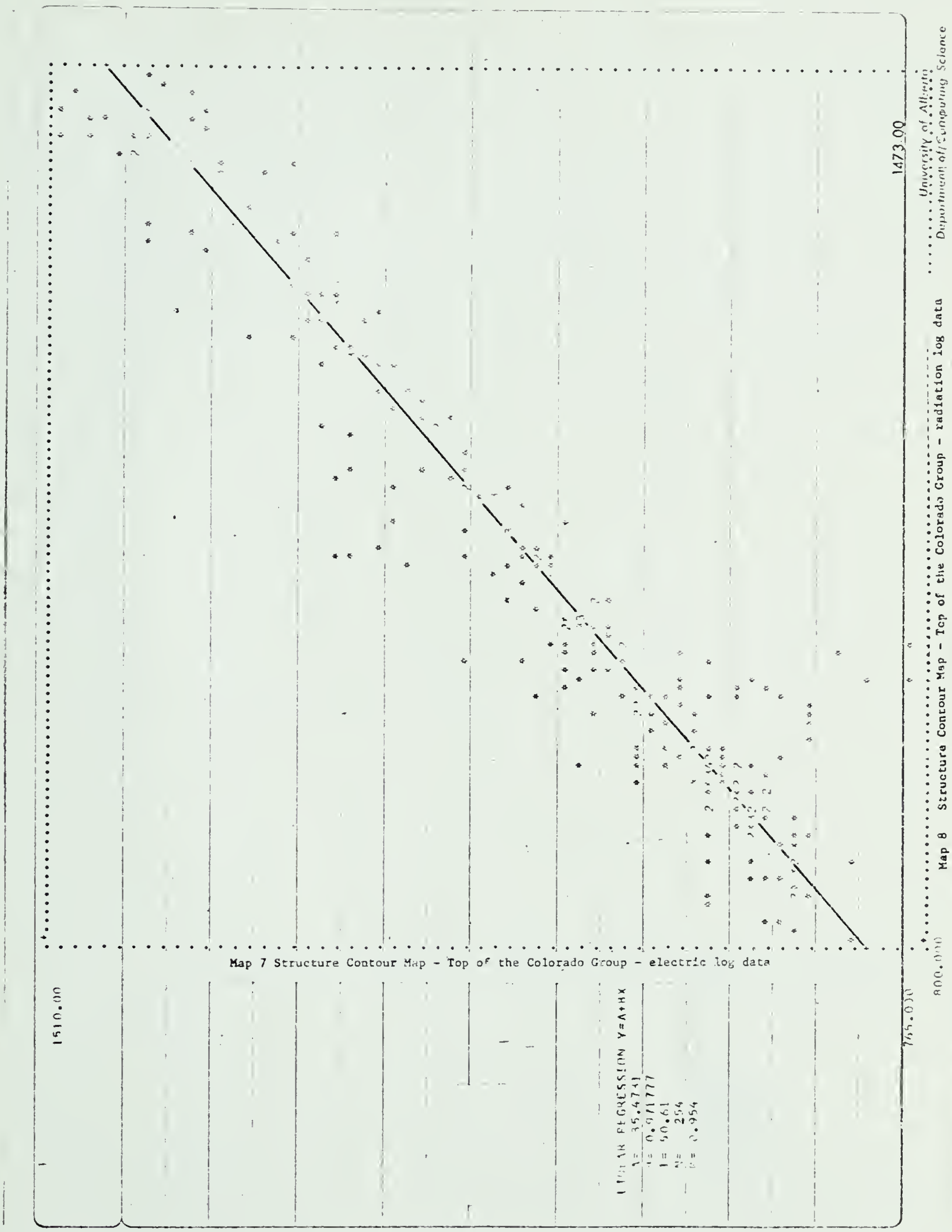

Map 3 Isopach Map - Medicine Hat Sandstone Member - electric log data

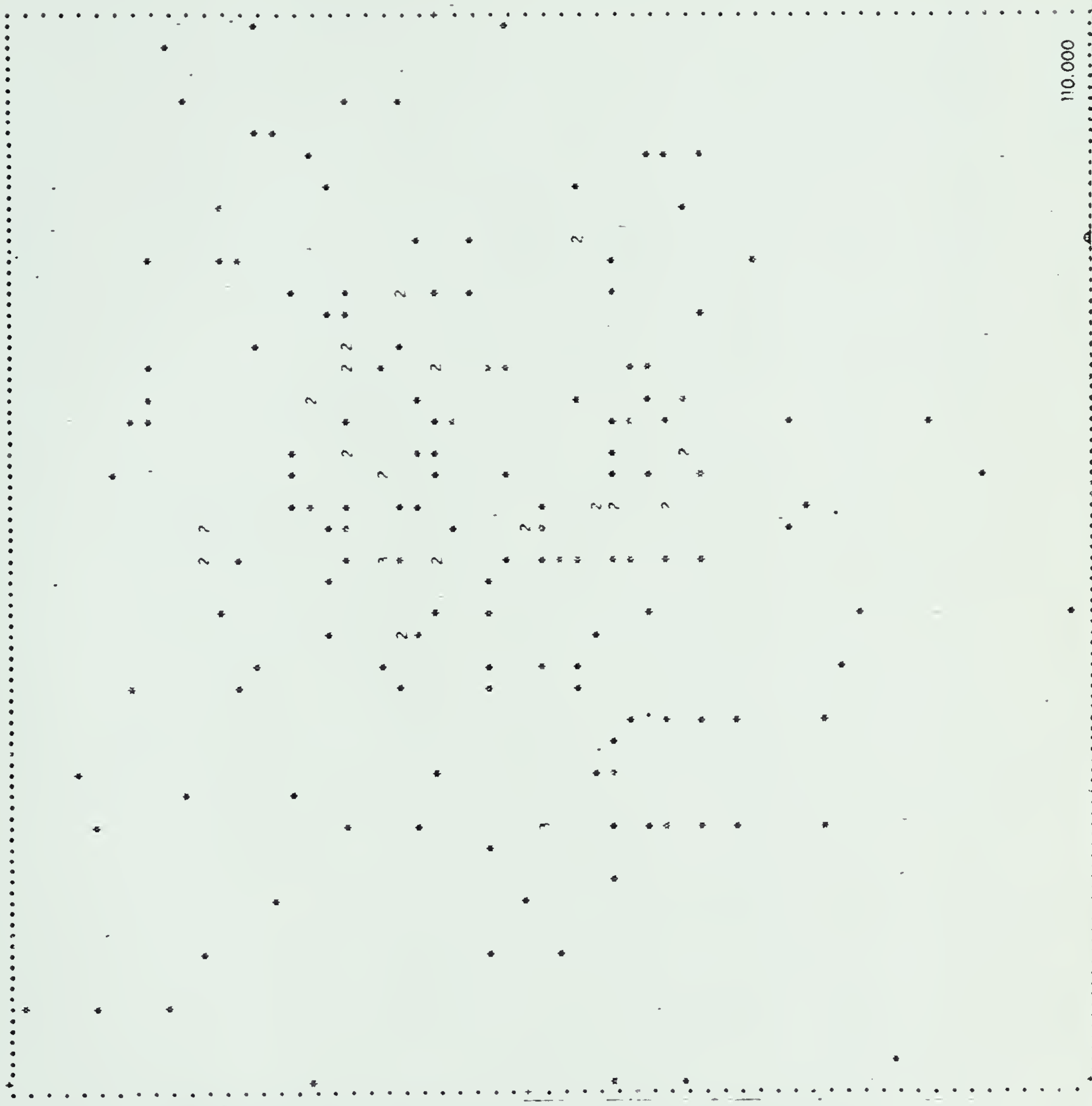
Map 4 Isopach Map - Medicine Hat Sandstone Member - radiation log data




Map 5 Structure Contour Map - Top of the Medicine Hat Sandstone Member - electric log data

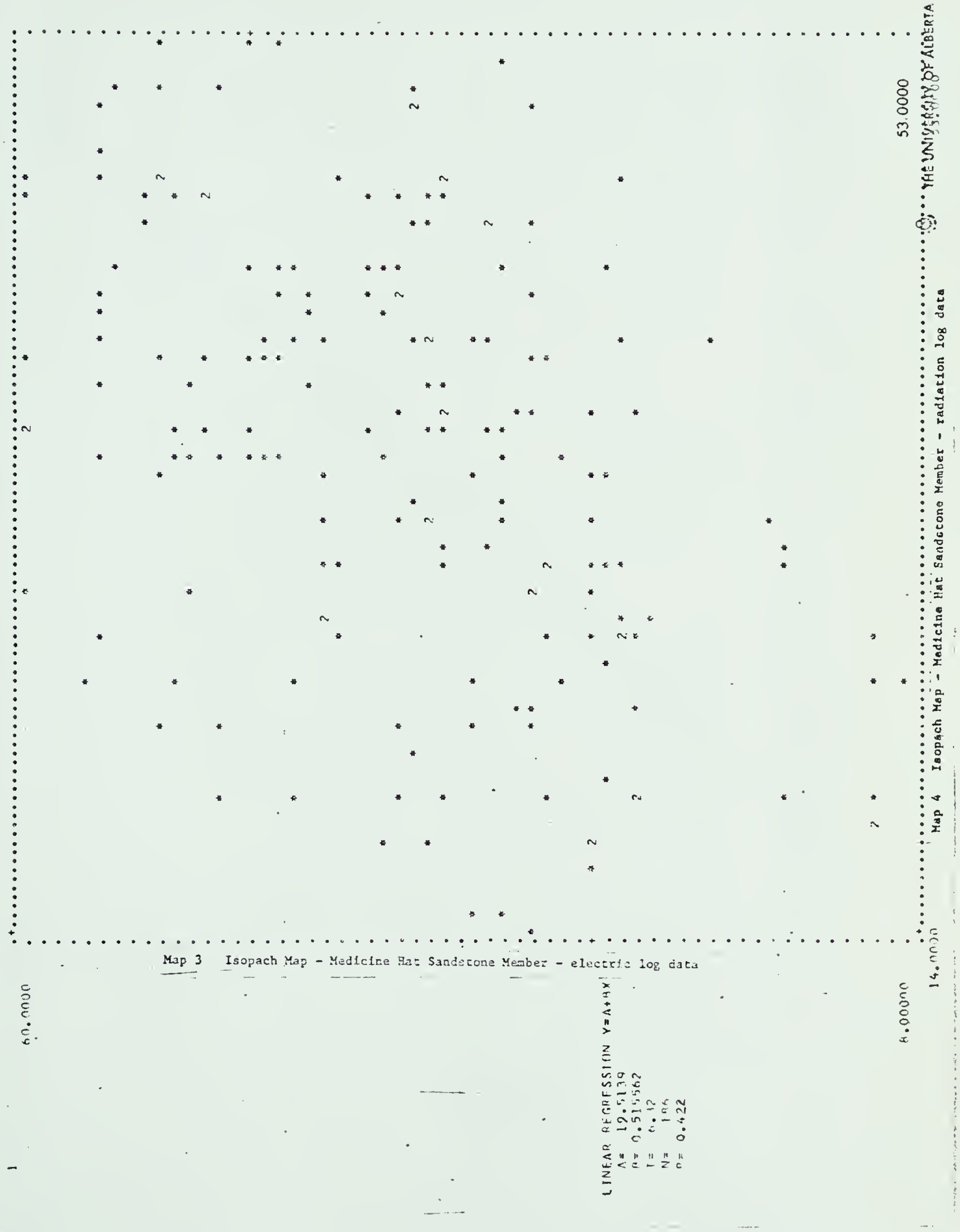
Map 6 Structure Contour Map - Top of the Medicine Hat Sandstone Member - radiation log data

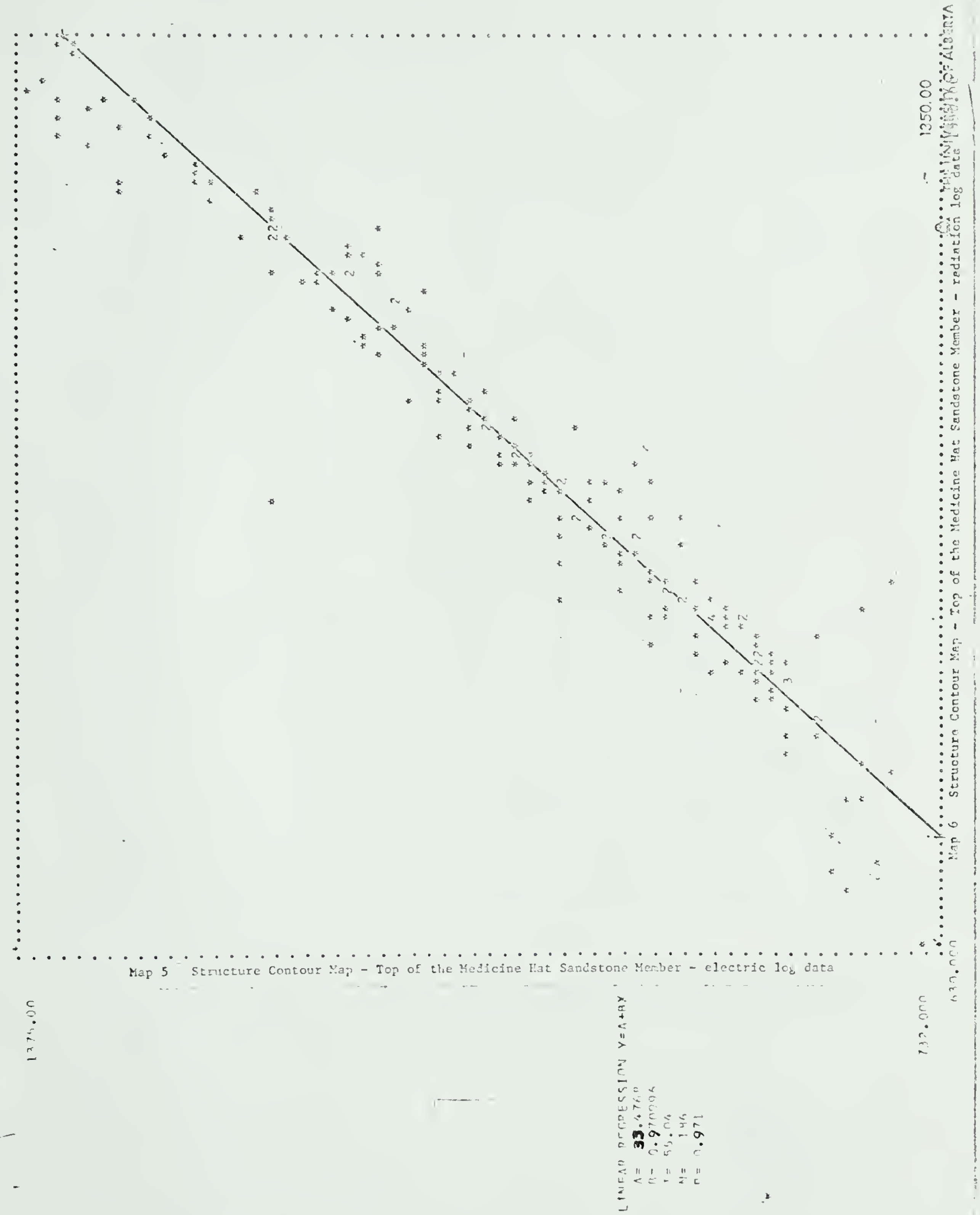

1510.00
1473.00
765.000
800.000
LINEAR REGRESSION Y=A+BX
A= 35.4731
B= 0.971777
S= 50.61
N= 254
R= 0.954
Map 7 Structure Contour Map - Top of the Colorado Group - electric log data
Map 8 Structure Contour Map - Top of the Colorado Group - radiation log data
University of Alberta
Department of Computing Science

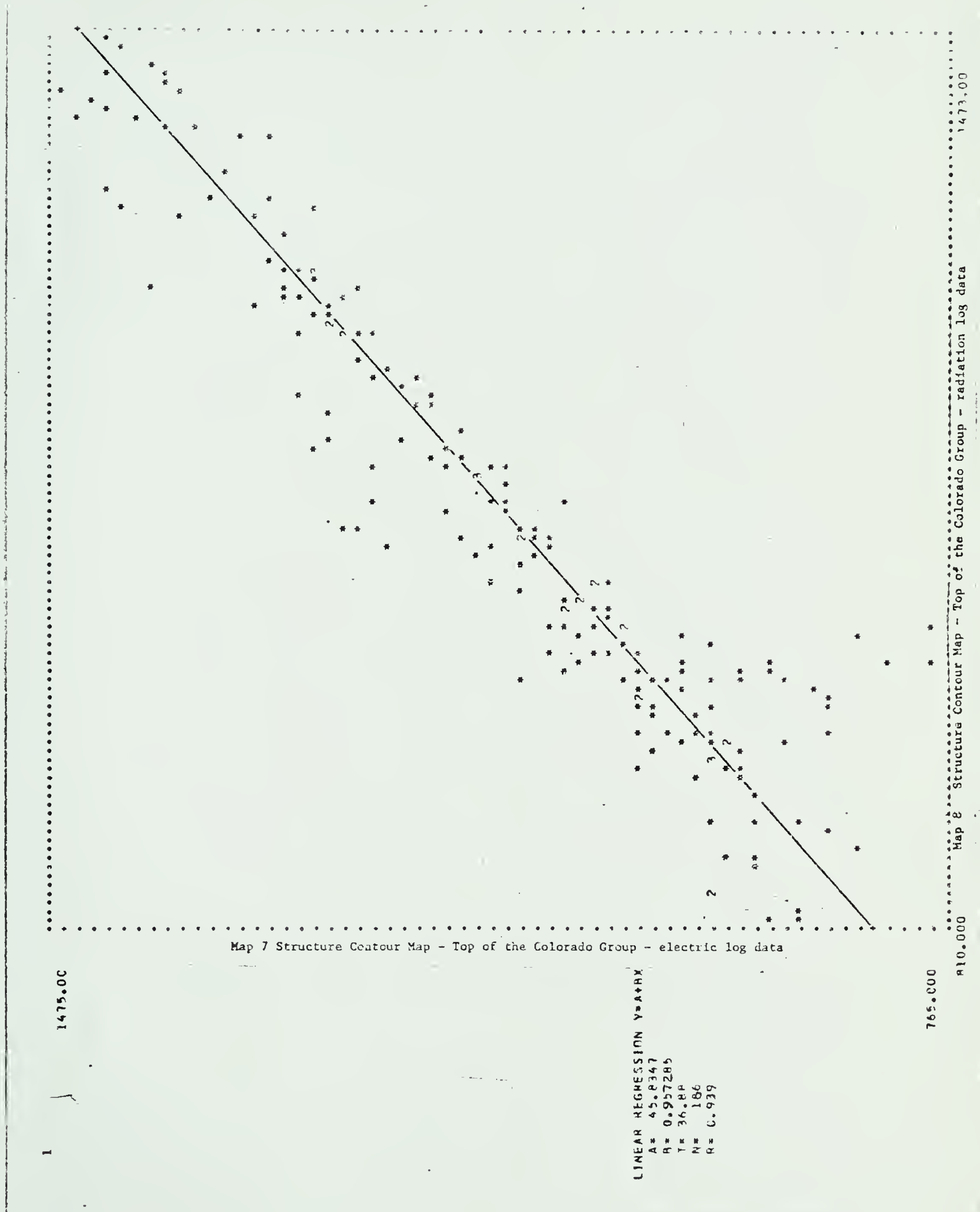



**Map 1** Isopach Map - Top Colorado Group to top Medicine Hat Sandstone Member - electric log data

**Map 2** Isopach Map - Top Colorado Group to top Medicine Hat Sandstone Member - radiation log data


Map 3 Isopach Map - Medicine Hat Sandstone Member - electric log data
Map 4 Isopach Map - Medicine Hat Sandstone Member - radiation log data
60.0000
8.00000
14.0000
53.0000
LINEAR REGRESSION Y=A+BX
A= 19.5139
B= 0.515562
R= 0.422


Map 5 Structure Contour Map - Top of the Medicine Hat Sandstone Member - electric log data
Map 6 Structure Contour Map - Top of the Medicine Hat Sandstone Member - radiation log data
1250.00
630.000
732.000
1375.00
LINEAR REGRESSION Y=A+BX
A= 33.4768
B= 0.970094
T= 55.04
N= 146
R= 0.971


1473.00
810.000
Map 8 Structure Contour Map - Top of the Colorado Group - radiation log data
Map 7 Structure Contour Map - Top of the Colorado Group - electric log data
1475.00
765.000
LINEAR REGRESSION Y=A+BX
A= 45.8347
B= 0.957285
T= 36.88
N= 186
R= 0.939


1404.00
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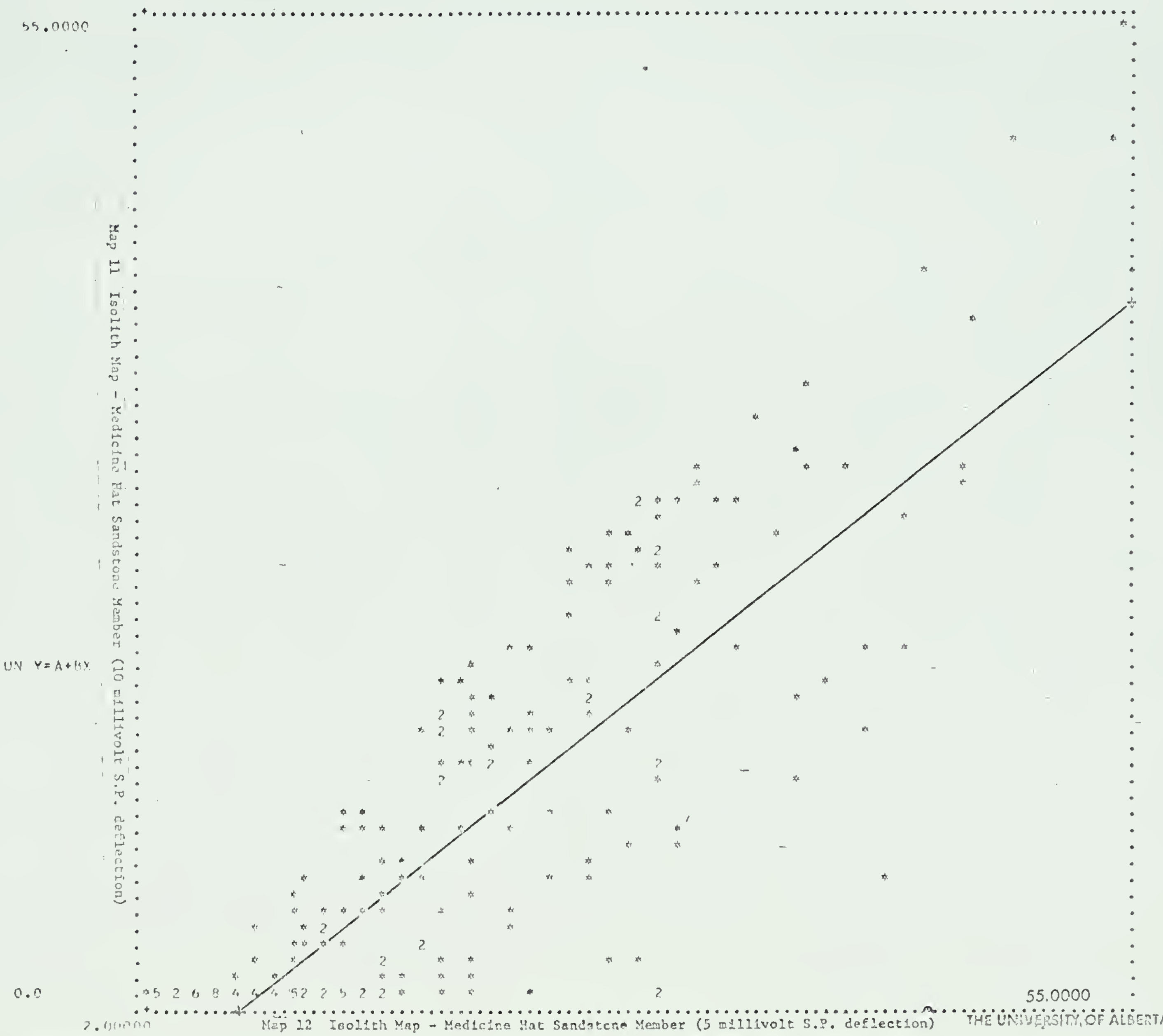
Map 5 Structure Contour Map - Top of the Medicine Hat Sandstone Member - electric log data
Map 7 Structure Contour Map - Top of the Colorado Group - electric log data
1505.00
717.000
605.000
LINEAR REGRESSION Y=A+BX
A= 92.4280
B= 0.998909
R= 0.997




LINEAR REGRESSION Y=A+BX
A= -6.08283
B= 0.842429
T= 21.74
N= 202
R= 0.838

# APPENDIX E

## Formulae for the Calculation of Mean, Standard Deviation and Correlation Coefficient

The program reads in each of the m observations on the n variables and accumulates the sums, sums of squares and sums of cross products as well as finding the minimums and maximums of each of the n variables.

The covariances are calculated according to the formula:

$$\mathrm{Cov}(X_i, X_j) = \frac{\sum_1^m x_i x_j - \frac{\sum_1^m x_i \sum_1^m x_j}{n}}{n-1} \qquad \text{where } j = 1, 2, \ldots, n \text{ and } i = j, j+1, \ldots, n$$

The standard deviations are calculated by finding the square root of the variables. Since $\mathrm{Var}(X_i) = \mathrm{Cov}(X_i, X_i)$ the formula used is:

$$\mathrm{SD}(X_i) = \sqrt{\mathrm{Cov}(X_i, X_i)} \qquad \text{where } i = 1, 2, \ldots, n$$

The means are computed by

$$\bar{X}_i = \frac{\sum_1^m x_i}{n} \qquad \text{where } i = 1, 2, \ldots, n$$

The correlation coefficients are computed using the formula:

$$r_{ij} = \frac{\mathrm{Cov}(X_i, X_j)}{\mathrm{SD}(X_i)\mathrm{SD}(X_j)} \qquad \begin{array}{l} \text{where } i = 1, 2, \ldots, n-1 \\ \text{and } \quad j = i+1, i+2, \ldots, n \end{array}$$